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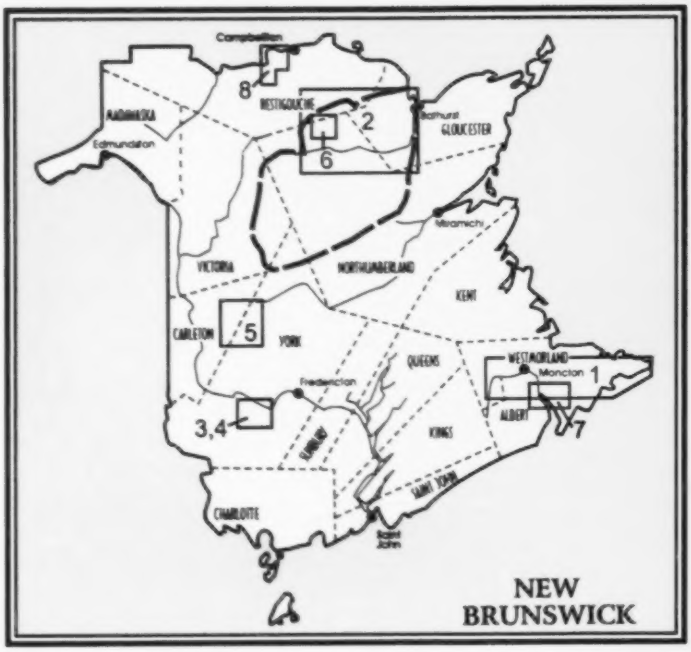
MRR 2002-4

New Nouveau
Brunswick

Natural Resources and Energy
Minerals, Policy and Planning

CURRENT RESEARCH 2001



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8. Geology, Squaw Cap area (R. Wilson)

⌒ Bathurst Mining Camp

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MIDDLE DEVONIAN QUARTZ MONZONITE FROM GAYTONS QUARRY AND LOWER COVERDALE DRILL CORE, MONCTON AREA, NEW BRUNSWICK †

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Barr, S.M., White, C.E. and Hamilton, M.A. 2002. Middle Devonian quartz monzonite from Gaytons quarry and Lower Coverdale drill core, Moncton area, New Brunswick. *In* Current Research, 2001. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Mineral Resource Report 2002-4, pp. 1–10.

Quartz monzonite forms most of the rock exposed in quarries east and west of the Memramcook River near Gaytons, southeastern New Brunswick. It was also encountered at a depth of 1095 m in a drill hole at Lower Coverdale, 15 km to the west, and probably forms the basement recovered below 314 m and 927 m of Carboniferous cover in the Westmorland and Port Elgin wells, 15 and 40 km to the east, respectively. The rock has distinctive megacrysts of K-feldspar and plagioclase, and contains abundant titanite and apatite. It has relatively low SiO_2 content (62–64%), and high contents of TiO_2, P_2O_5, Ba, Sr, Nb, Zr, and Y. U–Pb (zircon) dating of samples from the Gaytons quarry and Lower Coverdale drill core yielded almost identical crystallization ages of 390.0 ± 0.5 Ma and 390.6 ± 1.0 Ma, respectively. Spatial association, magnetic anomalies, and chemical links suggest that ferrogabbro–anorthosite in the Lower Coverdale area is of similar age. Based on aeromagnetic anomalies, these plutons are part of a major east-trending belt, and were probably emplaced in zones of localized transtension, perhaps associated with juxtaposition of the Brookville and Avalon terranes.

L'adamellite constitue la majeure partie de la roche dénudée dans les carrières à l'est et à l'ouest de la rivière Memramcook près de Gaytons, dans le Sud-Est du NouveauBrunswick. On a également rencontré ce minéral à une profondeur de 1 095 mètres dans un trou de forage de Lower Coverdale, à 15 kilomètres à l'ouest. Il forme vraisemblablement le soubassement récupéré au-dessous de 314 mètres et de 927 mètres de la couverture du Carbonifère dans les puits Westmorland et Port Elgin, forés à 15 et 40 kilomètres à l'est, respectivement. La roche présente des mégacristaux particuliers de feldspath potassique et de plagioclase, et elle renferme une quantité abondante de titanite et d'apatite. Elle a une teneur relativement faible en SiO_2 (62 – 64 %) et des teneurs élevées en TiO_2, P_2O_5, Ba, Sr, Nb, Zr et Y. Une datation au U–Pb (à partir de zircon) d'échantillons de la carrière de Gaytons et de Lower Coverdale a attribué aux carottes des âges de cristallisation quasi identiques de 390,0 ± 0,5 Ma et 390,6 ± 1,0 Ma, respectivement. L'association spatiale, les anomalies magnétiques et les liens chimiques laissent supposer que le ferrogabbroanorthosite du secteur de Lower Coverdale est d'un âge analogue. À en juger d'après les anomalies aéromagnétiques, ces plutons font partie d'une ceinture importante orientée vers l'est et ils se sont probablement immobilisés dans des zones de transtension localisée, sans doute associées à la juxtaposition des terranes de Brookville et d'Avalon.

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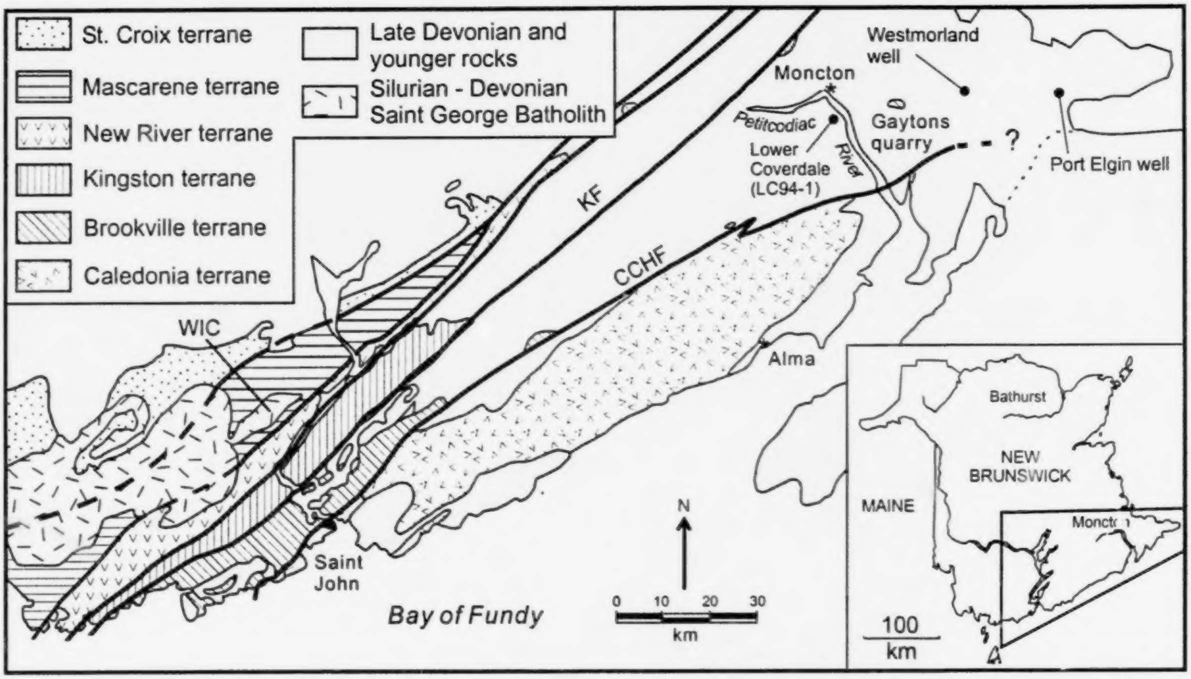

Figure 1. Terranes in southern New Brunswick, showing locations of the Gaytons quarry, Lower Coverdale hole # LC94-1, and the Westmorland and Port Elgin wells. Abbreviations: KF – Kennebecasis Fault; CCHF – Caledonia-Clover Hill Fault; WIC – Welsford Intrusive Complex.

INTRODUCTION

U–Pb (zircon) dating has shown that most plutons in the Caledonia and Brookville terranes of southern New Brunswick are of Late Neoproterozoic or Early Cambrian age (e.g., Barr and White 1999; Barr *et al.* 2001; Currie and Hunt 1991; Currie and McNicoll 1999; White and Barr 1996). However, quartz monzonite exposed in the Gaytons quarry near Memramcook and encountered in drill core in the Lower Coverdale area south of Moncton (Figure 1) are exceptions, as demonstrated by the U–Pb (zircon) ages presented in this paper. Similarity in their ages and petrographic and chemical characteristics demonstrate that these plutons are related. Magnetic maps of the area (e.g., Nickerson 1994) suggest that these plutons are part of a belt that trends east–west from the Moncton area to the Port Elgin area, where cuttings from drill core suggest that similar rocks are present. The purpose of this paper is to draw attention to these unusual rocks, and to present preliminary petrochemical and U–Pb data.

GEOLOGICAL SETTING

Southern New Brunswick is characterized by long narrow northeast-trending belts of rocks of contrasting composition and age, separated by major faults (Figure 1). One of these belts, termed the Brookville terrane (White and Barr 1996), is located between the Caledonia–Clover Hill fault on the southeast and the Kennebecasis fault on the northwest (Figure 1). The metasedimentary and plutonic rocks that characterize the Brookville terrane are well exposed in the Saint John area, and can be traced on the basis of sparse outcrops to the northeast through the Moncton area (White 1996; White and Barr 1996). Based on this projection, the Lower Coverdale area and the Gaytons quarry are located in the Brookville terrane (Figure 1). However, the extent of this terrane to the east of the Gaytons area is uncertain.

GAYTONS QUARRY

Large quarries have been excavated on both sides of the Memramcook River north of the community of Gaytons (Figure 2a). The main rock type in both quarries is granitoid rock with large phenocrysts of both K-feldspar (microcline) and plagioclase in a coarse-grained groundmass of mainly plagioclase, quartz, biotite (6–7%), and amphibole (3–4%) (Figure 2b). Accessory minerals are abundant, especially titanite, apatite, and opaque minerals (Figure 3a, 3b). Modal analysis on stained slabs of 9 samples (White 1996) showed that the compositions cluster near the intersection of the quartz monzodiorite, quartz monzonite, granodiorite, and monzogranite fields on the classification diagram of Streckeisen (1976) (Figure 4). For simplicity, the name quartz monzonite is used here, as it best reflects the relatively low quartz and approximately equal K-feldspar and plagioclase abundances in the rock.

In the northern part of the quarry west of the river, the porphyritic quartz monzonite is intruded by finer grained monzogranite that contains abundant fluorite patches and veins. Fluorite also occurs but is less abundant in the quartz monzonite. Both units are cut by rare dykes of intermediate (monzodiorite/monzonite) composition, which contain abundant biotite.

LOWER COVERDALE DRILL CORE

Petroleum exploration wells drilled in the Lower Coverdale area in 1919 and 1931 by NB Gas and Oilfields Limited and in 1970 by Killarney Oil and Gas encountered plutonic igneous rocks generally described as "granite" at depths of 100–200 m below Carboniferous sedimentary rocks. Subsequent drilling by Noranda Exploration in 1994, 1995, and 2001 showed that the rocks are mainly gabbro and anorthosite, with high titanium, phosphorus, and vanadium contents (Woods 1995; McHattie 1998; Moreton 2001). However, one of the holes, LC94-1, encountered coarse-grained granitic rock at a depth of 1095.6 m, in sheared contact with reddened and altered anorthosite. The granitic rock is also highly sheared and altered near the contact and, hence, the nature of the contact is uncertain. The granitic rock is very coarse-grained, and relatively homogeneous to the bottom of the hole at 1206.4 m.

Thin section study shows that the granitic rock throughout the 1095.6 m to 1206.4 m section of the core is brecciated and sheared, with abundant veins of carbonate and epidote. The most abundant minerals are plagioclase and K-feldspar (microcline), with less abundant granular quartz (Figure 3c, 3d). Because of the amount of alteration, coarse grain size and small sample size, accurate modal analysis is not possible, but estimates suggest that the rock is quartz monzonite like that in the Gaytons quarry. Original mafic minerals are now mostly replaced by chlorite, but big grains of titanite and apatite are abundant.

WESTMORLAND AND PORT ELGIN WELLS

Two wells drilled east of the Gaytons quarry (Westmorland and Port Elgin, Figure 1) encountered granitic basement. The Westmorland well, drilled in 1950 by Shell Oil Company and New Brunswick Oilfields Limited, encountered granitic rocks at a depth of 314 m, and the Port Elgin well, drilled in 1960 by Imperial Oil Limited and New Brunswick Oilfields Limited, reached granitic basement at about 927 m

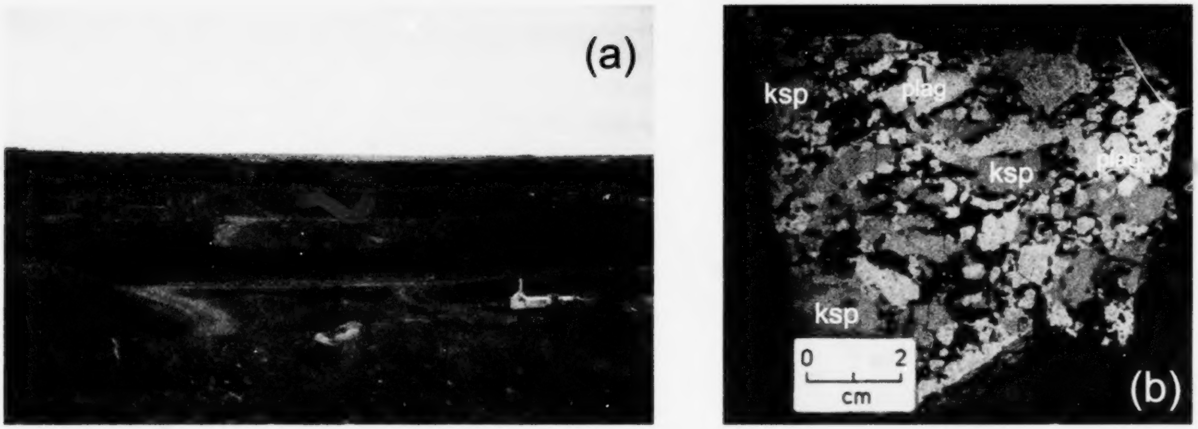

Figure 2. (a) View of the eastern part of the Gaytons quarry, looking east across the Memramcook River. (b) A hand specimen slab to illustrate the distinctive megacrystic texture of quartz monzonite from the Gaytons quarry (**ksp** – K-feldspar; **plag** – plagioclase; dark-coloured groundmass includes quartz and mafic minerals). Rock from this quarry is used widely along highways in southeastern New Brunswick and adjacent parts of Nova Scotia.

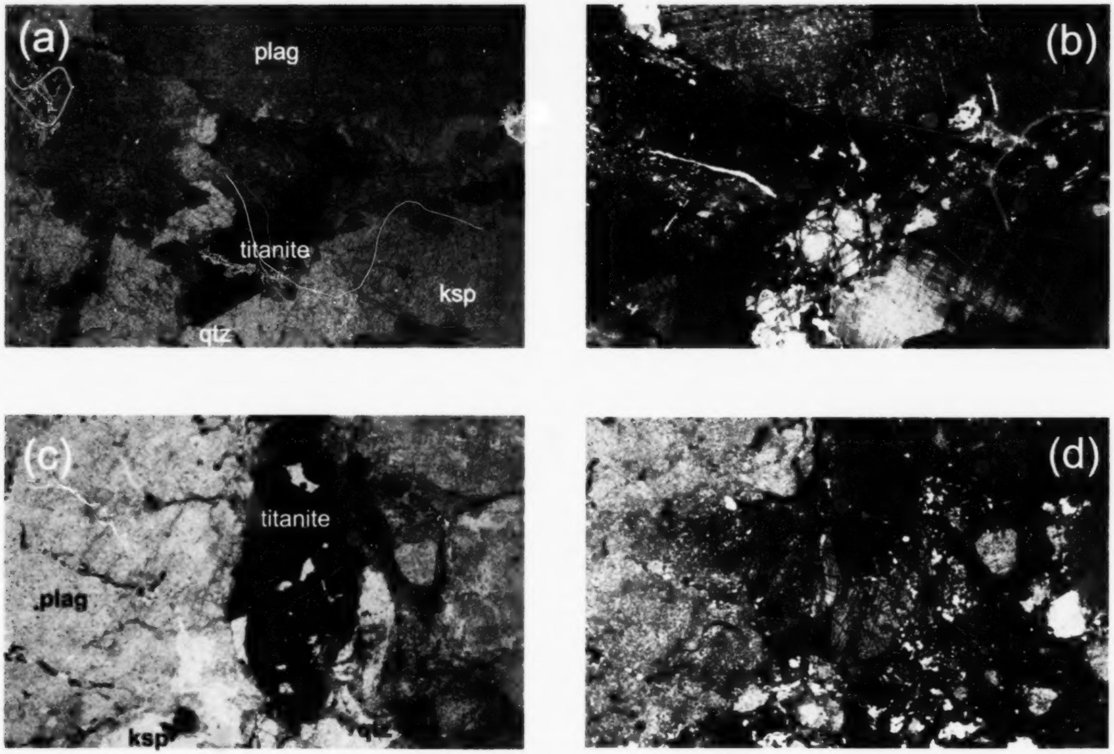

Figure 3. (a) Photomicrograph of a typical sample of quartz monzonite from the Gaytons quarry, showing micrcocline (**ksp**), plagioclase (**plag**), interstitial quartz (**qtz**), and a large titanite grain. (b) Same view in crossed polars. (c) Photomicrograph of a sample of quartz monzonite from drill hole LC94-1, depth 1174 m, showing typical brecciated texture. Minerals present include plagioclase (**plag**), microcline (**ksp**), quartz (**qtz**), and a large titanite grain. (d) Same view in crossed polars. Long dimension of all photos is approximately 4 mm.

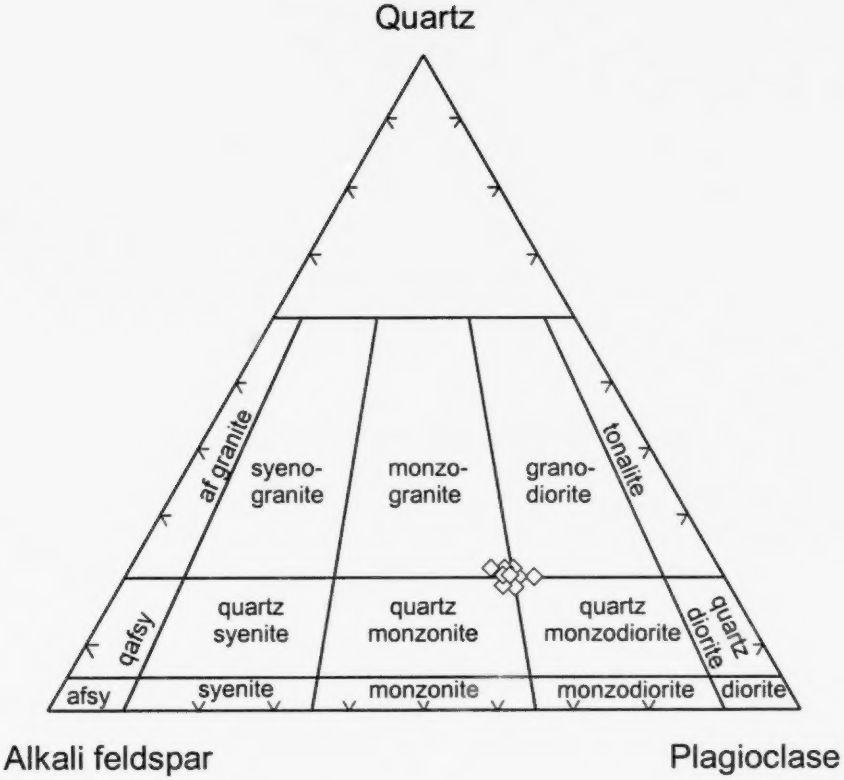

Figure 4. Modal analyses of 9 samples (◇) from the Gaytons quarry, plotted on the QAP diagram of Streckeisen (1976). Data are from White (1996). Abbreviations: af – alkali feldspar; qafsy – quartz alkali feldspar syenite; sy – syenite.

(St. Peter 1987). Thin sections made from chips from cuttings from both of these wells show mineral assemblages consistent with a quartz monzonite source, in that they contain abundant K-feldspar (microcline) and plagioclase, and less abundant quartz, as well as minor biotite and chlorite. In addition, the thin section from the Port Elgin well chips contains large grains of titanite like those observed in thin sections of quartz monzonite from both the Gaytons quarry and the Lower Coverdale core (Figure 3).

CHEMISTRY

Four samples, two from the Gaytons quarry and two from drill hole LC94-1, have been analyzed for major and selected trace elements. SiO_2 contents range between 62 and 64%, low values compared to typical granite, such as the average I-type granite shown for comparison on Figure 5. However, they are consistent with the relatively low modal quartz content in the quartz monzonite samples compared to granite (Figure 4). The SiO_2 values are similar to those in granodiorite such as that of the Cambrian Rockwood Park pluton of the Saint John area, two analyses from which are also shown for comparison on Figure 5. However, compared to granodiorite, the Gaytons quarry and LC94-1 samples have higher K_2O, which is similar to that in the average I-type granite (Figure 5f). Other chemical features characteristic of the four samples compared to the average I-type granite include lower Rb and Pb, and higher Ba, Sr, Nb,

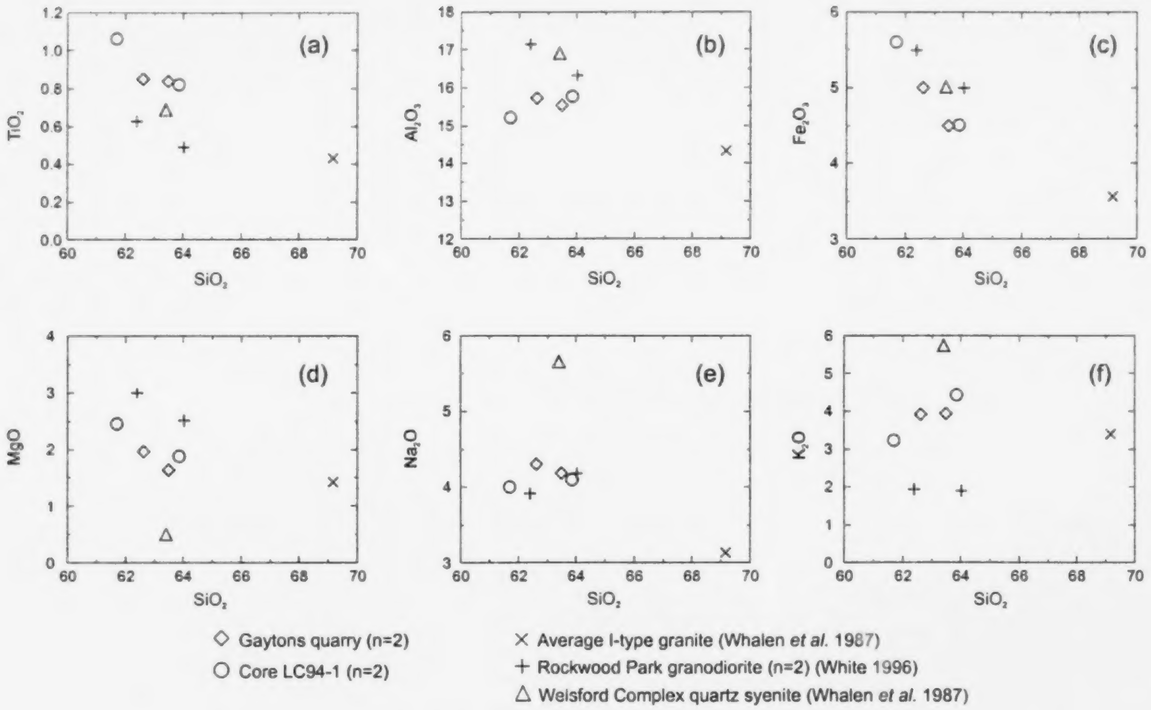

Figure 5. Plots of (a) TiO_2, (b) Al_2O_3, (c) $Fe_2O_3^t$, (d) MgO, (e) Na_2O, and (f) K_2O against SiO_2 to illustrate the chemical characteristics of the quartz monzonite from Gaytons quarry and the Lower Coverdale core compared to some other granitoid rocks, as discussed in the text.

Zr, TiO_2, and P_2O_5 (Figure 6). Figure 6 also illustrates the differences between the quartz monzonite samples and the Rockwood Park granodiorite, which in addition to K_2O is also lower in Ba, Sr, Nb, Zr, Y, TiO_2, and P_2O_5.

The distinctive chemical signature shared by the Gaytons quarry and Lower Coverdale core samples is consistent with their petrographic similarities described above, and further supports a correlation between the two bodies. Furthermore, the high TiO_2 and P_2O_5 contents, reflected in the abundance of modal titanite and apatite, suggests a genetic relationship to the Lower Coverdale gabbro–anorthosite complex.

The elevated concentrations of elements such as Nb, Zr, and Y in the quartz monzonite suggest affinities to A-type granitoid suites, which are also characterized by high abundances of those elements compared to other granitoid rocks (e.g., Whalen *et al.* 1987). Most members of A-type suites are granites with high SiO_2 content (average 73.8%; Whalen *et al.* 1987) and, hence, not directly comparable to the low-SiO_2 Gaytons quarry and Lower Coverdale core samples. However, Whalen *et al.* (1987) reported chemical data for quartz syenite from the Welsford Intrusive Complex, an A-type granitoid pluton that forms the eastern part of the Saint George Batholith in southern New Brunswick (Figure 1). This rock has SiO_2 content comparable to SiO_2 values in the Gaytons quarry and Lower Coverdale core samples, but has higher Al_2O_3, Na_2O and K_2O contents (Figure 5b, 5e, 5f) and lower TiO_2 and MgO contents (Figure 5a,

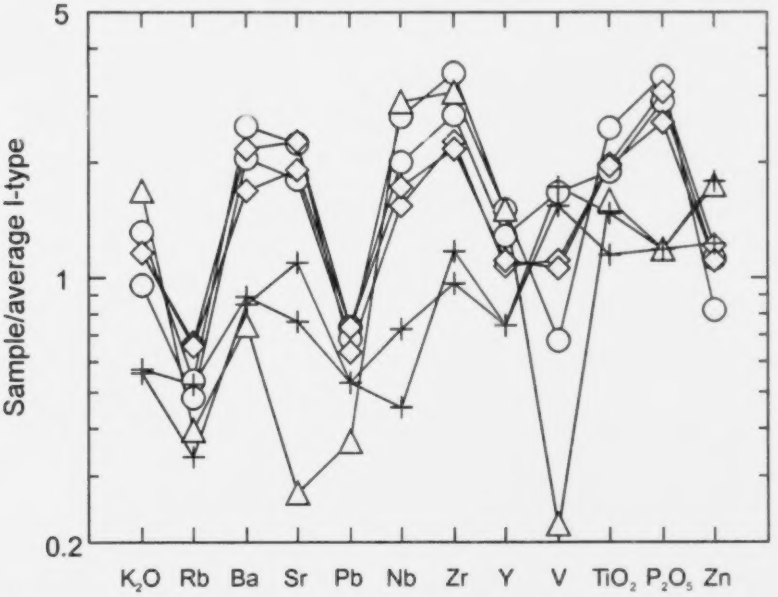

Figure 6. A multi-element variation diagram to illustrate chemical features of the quartz monzonite samples from the Gaytons quarry and the Lower Coverdale core compared to some other granitoid rocks. Data are normalized against the average I-type granite of Whalen *et al.* (1987). Symbols are the same as in Figure 5.

5d), consistent with its syenitic composition. Additional differences include lower Rb, Ba, Sr, Pb, and P_2O_5 (Figure 6). The Welsford Intrusive Complex is also significantly older (U–Pb zircon age 422 ± 1 Ma; Bevier 1990) than the quartz monzonite in the Lower Coverdale–Gaytons quarry area (see below).

U–PB (ZIRCON) AGES

Correlation between quartz monzonite in the Gaytons quarry and that in hole LC94-1 is further supported by their similar U–Pb ages. Three fractions of water-clear, colourless to very pale pinkish brown and yellow–brown elongate zircon prisms (length:width = 2:1 to 4:1) were analyzed from a drill-core sample from LC94-1. Most grains contained small numbers of rounded, irregular fluid inclusions. All of the fractions cluster on or near concordia, and yield a weighted mean $^{206}Pb/^{238}U$ age of 390.6 ± 1.0 Ma (Figure 7a), interpreted to be the time of crystallization of the Lower Coverdale quartz monzonite. A sample from the Gaytons quarry yielded similar-looking zircon grains (also rich in fluid inclusions) as well as a population of stubby, flat, sharply terminated prisms. Three fractions were analyzed and show nearly identical Pb/U ages, with error ellipses overlapping each other and concordia (Figure 7b). A weighted mean $^{206}Pb/^{238}U$ age of all three clustered analyses is 390.0 ± 0.5 Ma, interpreted to represent the crystallization age of the Gaytons quartz monzonite.

The complete data set and more detailed interpretation will be published elsewhere.

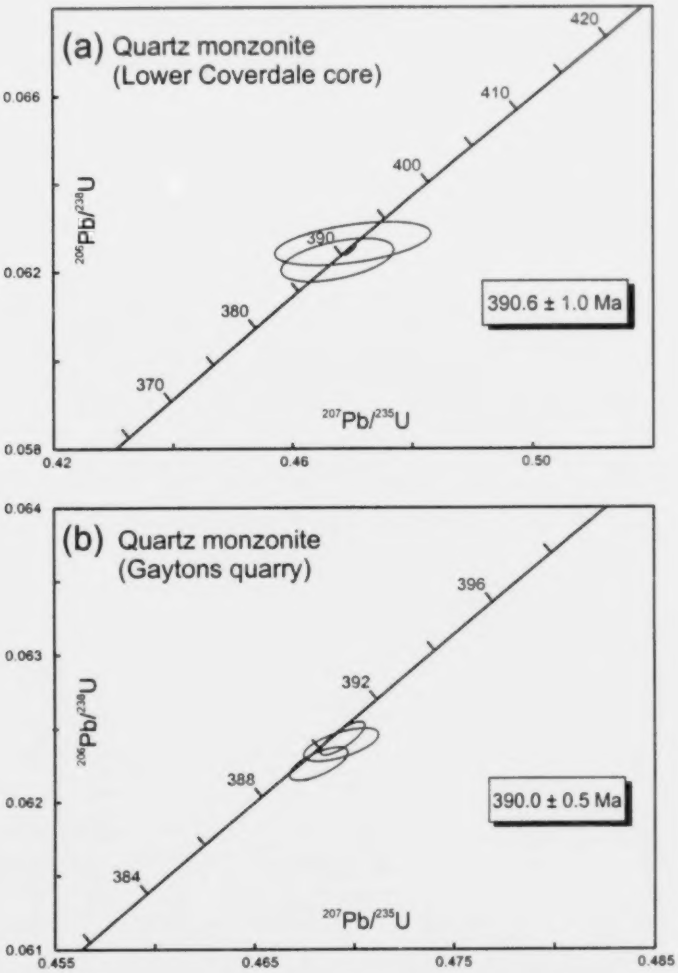

Figure 7. U–Pb concordia diagram for (a) quartz monzonite drill hole LC94-1 and (b) quartz monzonite from the Gaytons quarry. Analyses were carried out by M. Hamilton at the Geological Survey of Canada, Ottawa. Data tables and detailed interpretation will be published elsewhere.

IMPLICATIONS AND CONCLUSIONS

Petrographic and chemical studies, together with U–Pb dating of zircon, confirm that the quartz monzonite that forms most of the Gaytons quarry is the same as that encountered at a depth of 1095 m below gabbro and anorthosite in drill hole LC94-1 in the Lower Coverdale area, 15 km to the west. Chips of mineralogically similar rock also form the "basement" encountered at a depth of about 314 m in the nearby Westmorland well and 910 m in the Port Elgin well, more than 35 km to the east (Figure 1). Although the quartz monzonite is not magnetic, this belt of basement rocks is associated with a series of magnetic anomalies. In the Lower Coverdale area, drilling has shown that the magnetic anomalies are caused by subsurface ferrogabbro bodies with concentrations of ilmenite and apatite (Woods 1995; Moreton 2001). A close association between the gabbro–anorthosite and the quartz monzonite is seen in Lower Coverale drill hole LC94-1, although the contact is sheared and an intrusive relationship cannot be demonstrated. Chemical features of the quartz monzonite such as high TiO_2 and P_2O_5 (reflected in the presence of abundant titanite and apatite) suggest a genetic link with the ferrogabbro–anorthosite units. The combination of spatial association and chemical links suggests that the ferrogabbro–anorthosite, like the quartz monzonite, has an age of ca. 390 Ma (mid-Devonian).

The east–west trend of this belt of mid-Devonian plutons is anomalous compared to the regional northeast-trending structural fabric of southern New Brunswick (Figure 1). It may suggest that the subsurface boundary between the Brookville and Caledonia terranes turns to this orientation east of the Petitcodiac River. Previously published Sm–Nd isotopic data indicated an epsilon Nd value of 0.3, indicating significant involvement of crust in the petrogenesis of the granite, a feature also characteristic of Cambrian plutons in the Brookville terrane (Samson *et al.* 2000). A-type (anorogenic) granitoid suites are generally emplaced during continental extension and rifting (Whalen *et al.* 1987). Prior to the recognition of its Late Silurian age, the Welsford Intrusive Complex was interpreted to represent rift-related magmatism during the Devonian Acadian orogeny (Payette and Martin 1988). The previously unknown Lower Coverdale–Port Elgin plutonic belt may be instead an example of Devonian extensional magmatism, whereas the Welsford Intrusive Complex represents an older (Silurian) extensional event.

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REFERENCES

Barr, S.M., and White, C.E. 1999. Field relations, petrology, and structure of Neoproterozoic rocks in the Caledonian Highlands, southern New Brunswick, Canada. Geological Survey of Canada, Bulletin 530, 101 p.

Barr, S.M., White, C.E., and Miller, B.V. 2001. Cambrian granitoid plutons of the Pocologan area and the continuation of the Brookville terrane to the Wolves Islands. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 15–24.

Bevier, M.L. 1990. Preliminary U–Pb geochronologic results for igneous and metamorphic rocks, New Brunswick. *In* Project summaries for 1989. Fourteenth Annual Review of Activities. *Compiled and edited by* S.A. Abbott. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 89-2, pp. 190–194.

Currie, K.L. and Hunt, P.A. 1991. Late Precambrian activity near Saint John, New Brunswick. *In* Radiogenic Age and Isotopic Studies. Report 4. Geological Survey of Canada, Paper 90-2, pp. 11–17.

Currie, K.L., and McNicoll, V.J. 1999. New data on the age and geographic distribution of Neoproterozoic plutons near Saint John, New Brunswick. Atlantic Geology, **35**: 157–166.

McHattie, T. 1998. Distribution and controls of titanium mineralization in the Lower Coverdale intrusion, New Brunswick. Unpublished B.Sc. Honours thesis, Saint Francis Xavier University, Antigonish, Nova Scotia.

Moreton, C. 2001. Assessment report on the Lower Coverdale property. (NTS 21 I/02 East). Report prepared for Noranda Inc. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 475430.

Nickerson, W.A. 1994. Geophysical constraints on the stratigraphy, structure, and tectonic evolution of the Late Devonian/Carboniferous Moncton Subbasin, New Brunswick, Canada. PhD thesis, Memorial University of Newfoundland, St. John's Newfoundland, 340 p.

Payette, C., and Martin, R.F. 1988. The Welsford anorogenic igneous complex, southern New Brunswick: rift-related Acadian magmatism. Geological Survey of Canada, Open File 1727, 346 p.

Samson, S.D., Barr, S.M., and White, C.E. 2000. Nd isotopic characteristics of terranes within the Avalon zone, southern New Brunswick. Canadian Journal of Earth Sciences, **37**: 1039–1052.

St. Peter, C. 1987. Catalogue of well data for boreholes in southern and eastern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File Report 87-15.

Streckeisen, A.L. 1976. To each plutonic rock its proper name. Earth Science Reviews, **12**: 1–33.

Whalen, J.B., Currie, K.L., and Chappell, B.W. 1987. A-type granites: geochemical characteristics, discrimination and petrogenesis. Contributions to Mineralogy and Petrology, **95**: 407–419.

White, C.E. 1996. Geology, geochronology, and tectonic evolution of the Brookville terrane, southern New Brunswick. Unpublished Ph.D. thesis, Dalhousie University, Halifax, Nova Scotia, Canada.

White, C.E. and Barr, S.M. 1996. Geology of the Brookville terrane, southern New Brunswick, Canada. *In* Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. *Edited by* R.D. Nance and M.D. Thompson. Geological Society of America, Special Paper 304, pp. 95–108.

Woods, G. 1995. Report of work – Lower Coverdale property. (NTS 21 I/02 East). Report prepared for Brunswick Mining and Smelting Corporation Limited. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Assessment File 474544.

THE DISCOVERY AND MINING OF MASSIVE ZINC–LEAD–COPPER–SILVER SULPHIDE DEPOSITS IN NEW BRUNSWICK — PAST AND FUTURE †

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CRANSTONE, D. 2002. The discovery and mining of massive zinc–lead–copper–silver sulphide deposits in New Brunswick — past and future. *In* Current Research 2001. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Mineral Resource Report 2002-4, pp. 11–40.

Massive Zn–Pb–Cu–Ag sulphide deposits have been mined in New Brunswick since soon after the Brunswick #6, Brunswick #12 and Heath Steele deposits were discovered in the period 1952 to 1954, and have remained the principal focus of mining and mineral exploration in the province since then. This report presents all the data that the author has been able to compile from a variety of sources, for massive sulphide deposits in the province, concerning exploration expenditures, mineral discoveries, metal production, grades of annual ore production, ore reserves, metallurgical recovery percentages, and the outlook for the future. Some of the exploration expenditure data for the province presented here have not been published before.

On a commencé à exploiter des gîtes de sulfures massifs de Zn–Pb–Cu–Ag au Nouveau-Brunswick peu après la découverte des gisements Brunswick n° 6, Brunswick n° 12 et Heath Steele au cours de la période de 1952 à 1954. Ces gîtes sont demeurés le principal point de mire de l'extraction minière et de l'exploration minérale dans la province depuis lors. Ce rapport présente toutes les données que l'auteur a pu compiler à partir de diverses sources relativement aux gîtes de sulfures massifs de la province en ce qui concerne les dépenses d'exploration, les découvertes de minéraux, la production de métaux, les teneurs commerciales des minerais produits chaque année, les réserves de minerais, les pourcentages de récupération métallurgique et les perspectives d'avenir. Certaines des données provinciales sur les dépenses d'exploration présentées dans ce document n'ont jamais été publiées auparavant.

INTRODUCTION

Massive zinc–lead–copper–silver sulphide deposits have constituted the principal focus of mineral exploration and mining in New Brunswick ever since the discovery of the Brunswick #6 deposit (in 1952), the Brunswick #12 deposit (in 1953), the Heath Steele deposit (in 1954), the Caribou deposit (in 1955), and the Wedge deposit (in 1957). Initial production from these deposits occurred in 1957 — Heath Steele mine, 1962 — Wedge mine, 1964 — Brunswick #12 mine, 1966 — Brunswick #6 mine, and 1970

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† This paper is based on a talk having the same title, presented by the author at Minerals and Energy Division's "Review of Activities," November 2, 1998 in Fredericton. The present paper summarizes that talk and, in addition to updated figures derived from the slides used in the talk, also presents much of the basic statistical data (much of it previously unpublished) on which they are based. Where possible, data have been updated to the end of 2000.

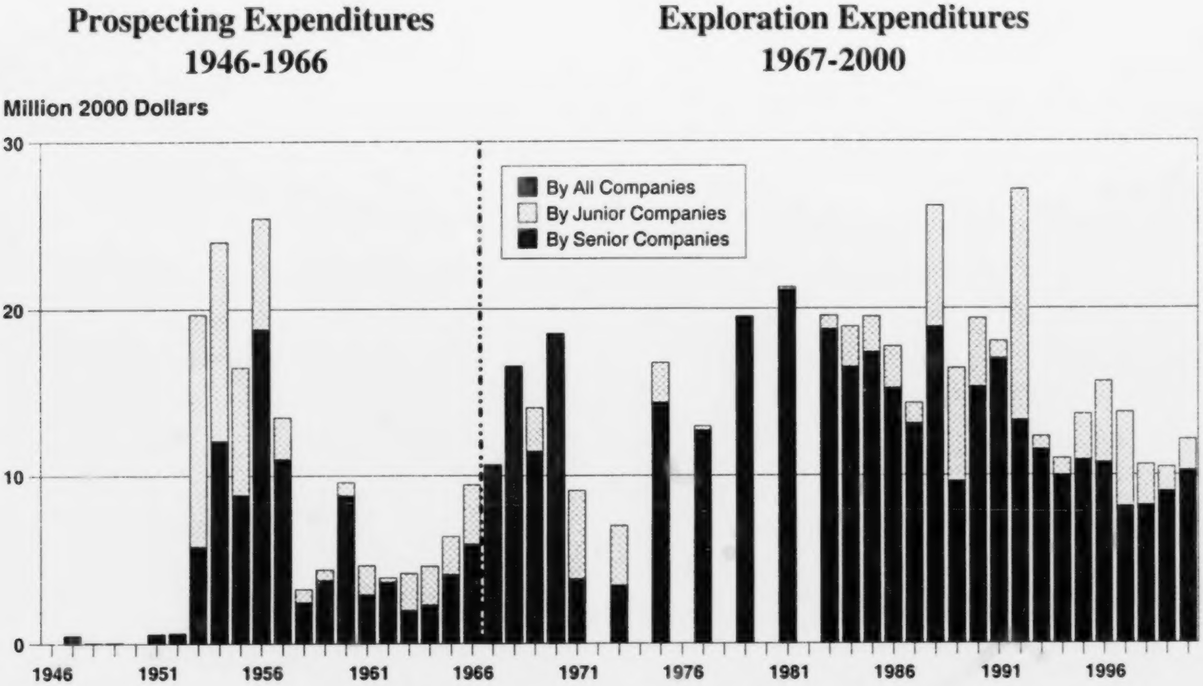


Figure 1. Prospecting and exploration expenditures in New Brunswick.

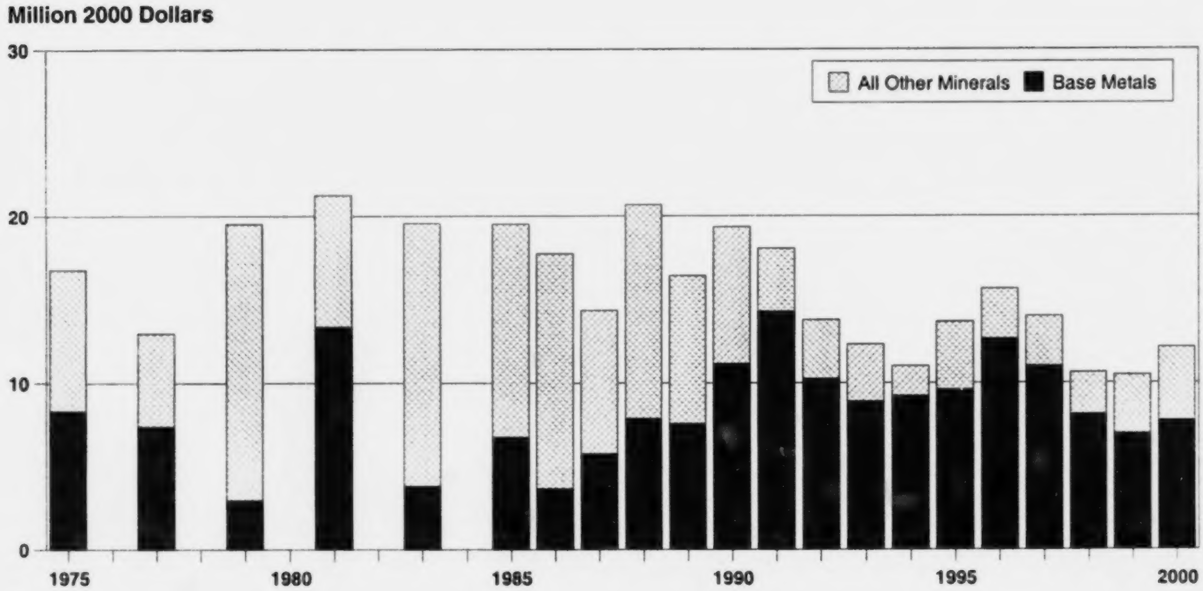


Figure 2. Exploration expenditures in New Brunswick for the base metals.

— Caribou mine. Several other smaller massive Zn–Pb–Cu–Ag sulphide deposits have also yielded some production.

Massive sulphides have remained the focus of mining and mineral exploration in New Brunswick since the 1950s. Today the Wedge, Brunswick #6 and Heath Steele deposits have all been mined out, and the Brunswick #12 mine is expected to be mined out by about 2010. Unacceptable metallurgical recoveries and low metal prices continue to prevent mining of the Caribou deposit, despite four separate but unsuccessful attempts since 1970 to bring it into economic production.

This report presents all the data that the author was able to compile, from a variety of sources, for New Brunswick exploration and mining, concerning exploration expenditures, discoveries, metal production, average grades of annual ore production, annual metallurgical recoveries and annual ore reserves. Some of the exploration expenditure data for New Brunswick has not been published previously.

EXPLORATION EXPENDITURES

Prospecting and mineral exploration expenditures in New Brunswick have been subdivided into expenditures by senior companies and those by junior companies (Tables 1 and 2, Figure 1). Much of this information cannot be found in any public source, but has been compiled by the author using data obtained from the original questionnaires filled out by companies and returned to Statistics Canada. Some explanation of the sources of these data is needed.

For twenty-one years, from 1946 to 1966 inclusive, Statistics Canada (originally the Dominion Bureau of Statistics) collected annual data concerning "prospecting expenditures by metal mining companies." The Statistics Canada totals included prospecting expenditures by both junior and senior companies. These prospecting expenditures do not include any prospecting carried out by companies that produced industrial minerals, coal or construction materials. There was no definition provided by Statistics Canada of what sorts of expenditures should be included in prospecting expenditures, so it is not known exactly what the prospecting totals include. Prospecting expenditures by metal mining companies were published by Statistics Canada for years 1946 to 1963 inclusive. Different numbers ("prospecting expenditures by producing metal mining companies") were published for 1964 and 1965, but these did not include the prospecting expenditures of non-producing companies, nor those of the exploration subsidiaries of producing companies such as Canadian Nickel Company (Inco Ltd.), Hudson Bay Exploration and Development (Hudson Bay Mining and Smelting) or Dome Exploration (Dome Mines), so had no real significance. Prospecting expenditures for 1966 were never published.

As the exploration questionnaires were joint ones from Statistics Canada and Natural Resources Canada, the author has had access to the individual questionnaires that were returned to Statistics Canada by all the companies that prospected in New Brunswick. This made it possible to compile comparable, previously unpublished, prospecting expenditures by metal mining companies for the years 1964, 1965 and 1966 as well as to compile separate prospecting totals for senior companies and for junior companies over the interval 1946 to 1966.

In 1967, the "prospecting" survey was replaced by a new exploration survey. This new survey gathered exploration expenditures for all non-petroleum mineral commodities by all types of companies, with the

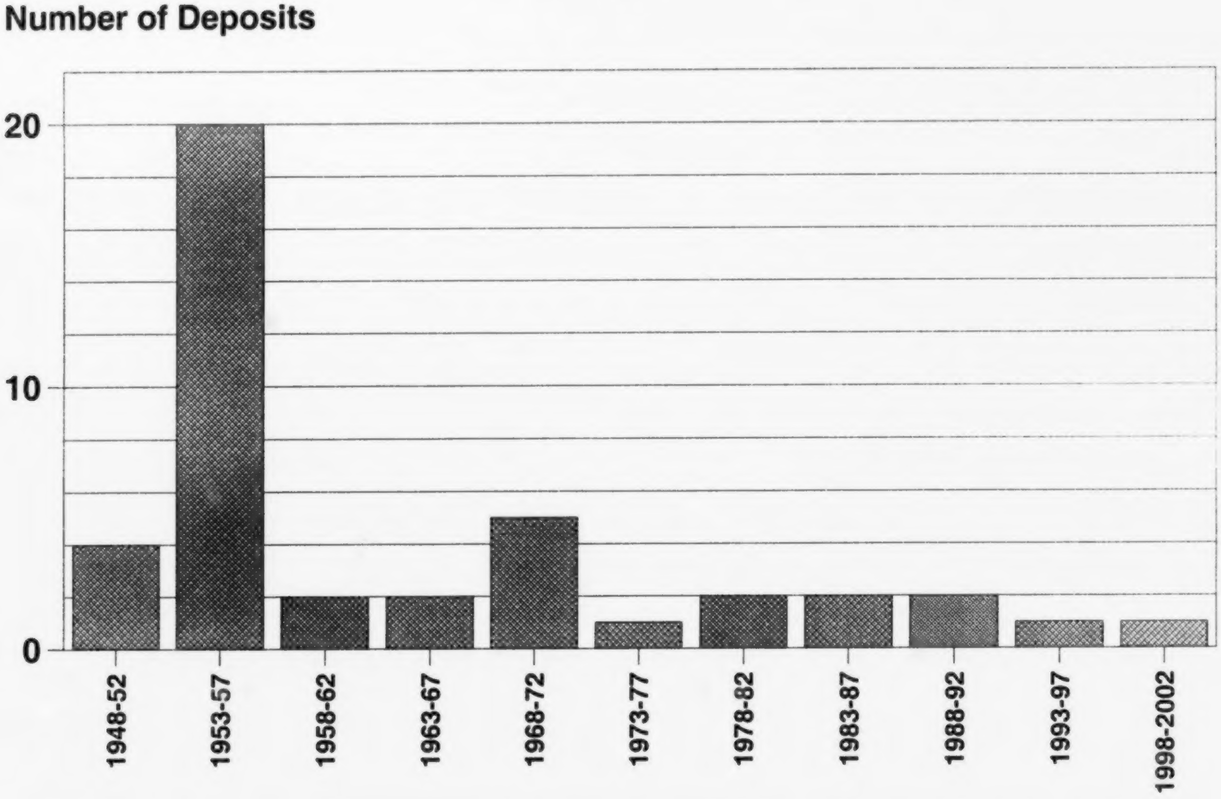


Figure 3. Number of massive sulphide deposits discovered in New Brunswick per 5-year period.

expenditures subdivided into "General Exploration" and "Minesite Exploration"(exploration on the properties surrounding producing mines, but not in the mines). As would be expected, this new survey, which covered all non-petroleum minerals generally resulted in an increase in total reported annual exploration expenditures relative to the former prospecting expenditures survey.

To preserve confidentiality of data in provinces where there were few mines, exploration expenditures and other mining statistics were combined for the four "Atlantic Provinces," for the three "Prairie Provinces," and for the two "Northern Territories." For this reason, exploration expenditure statistics were not published, nor even available, for New Brunswick alone, but were included in the combined totals for the Atlantic Provinces for the period 1971 until 1985.

As with the prospecting expenditures questionnaires, Natural Resources Canada's name was also on the exploration expenditures questionnaires, so Natural Resources Canada was also able to obtain and use those questionnaires. Data were extracted by the author that permitted compilation of New Brunswick exploration expenditures for some of the missing years, both for junior companies and for senior companies separately. Such data are not available for even-numbered years, 1970 to 1984 inclusive, because the questionnaires for those years were destroyed by Statistics Canada before Natural Resources Canada requested them.

In 1985, Natural Resources Canada and some participating provinces took over from Statistics Canada the gathering of most Canadian exploration statistics. Since then, annual exploration statistics specific to New Brunswick have been gathered and published, in considerable detail, by the Federal–Provincial Exploration Survey (until 1996) and the subsequent Federal–Provincial Survey of Mineral Exploration, Deposit Appraisal and Mine Complex Development Expenditures (for 1997 and subsequent years).

Beginning with 1975, Statistics Canada added a question concerning what commodity or commodities companies were exploring for, but these data were never compiled by Statistics Canada. The author compiled the data concerning expenditures for the various commodities explored for by companies, from the Statistics Canada questionnaires, for odd-numbered years from 1975 to 1983 inclusive, including exploration expenditures for base metals (Table 3, Figure 2). Published Federal–Provincial Exploration Survey data, which include a compilation of exploration expenditures for base metals, are available annually beginning with survey year 1985. An exploration expenditure commodity breakdown is not available for 1976, 1978, 1980, 1982 or 1984.

Figures 1 indicates that exploration expenditures in New Brunswick infrequently exceeded $10 000 000 (year 2000 dollars) from 1958 until 1975, but were never below this number after 1975. Furthermore, Figure 2 shows that more than half the expenditures were for base metals for many of the years after 1975.

DISCOVERIES

Some 42 massive base-metal sulphide deposits have been discovered in the Bathurst District since 1952 (Figure 3). The first major discoveries were the result of ground follow-up of anomalies revealed by the then newly developed airborne geophysical surveying techniques. Figure 3 shows the number of massive sulphide deposits discovered in New Brunswick in each five-year period over the 55-year interval 1948–2002. In terms of the number of discoveries, the period 1953–1957 stands out from all other periods. It stands out even more if one looks at the quantities of metal that were discovered in each five-year period. Figures 4a to 4d indicate tonnes of zinc, lead, copper and silver discovered in New Brunswick in each of the five-year periods. Almost all the significant massive sulphide deposits found in the province were discovered in the six years 1952 to 1957. The Brunswick #6 deposit, discovered in 1952, accounts for most of the zinc discovered in 1948–1952. The discovery period, 1953–1957 includes the Brunswick #12, Heath Steele, Caribou and Wedge orebodies, the original Stratmat discovery, part of the Halfmile Lake deposit and another 14 deposits. Only relatively minor discoveries were made in all subsequent five-year periods until 1983–1987. The period 1983–1987 includes additional tonnages that were discovered at Halfmile Lake, and the Stratmat S-1 deposit.

Noranda discovered mineralization at Camel Back in 1996 or 1997, but Camel Back appears to be more a mineral occurrence than a deposit. As no information is available concerning the tonnage and grades of Camel Back, it is not included in the figures that depict the tonnages of metals discovered. The Mount Fronsac deposit, discovered in 2001, is the only massive base-metal sulphide deposit discovered to date in the period 1998–2002.

PRODUCTION

Figure 5 depicts annual quantities of zinc, lead and copper and silver contained in the ore that has been milled from the Brunswick #12 deposit each year since production began in 1964 (Table 4). The vertical

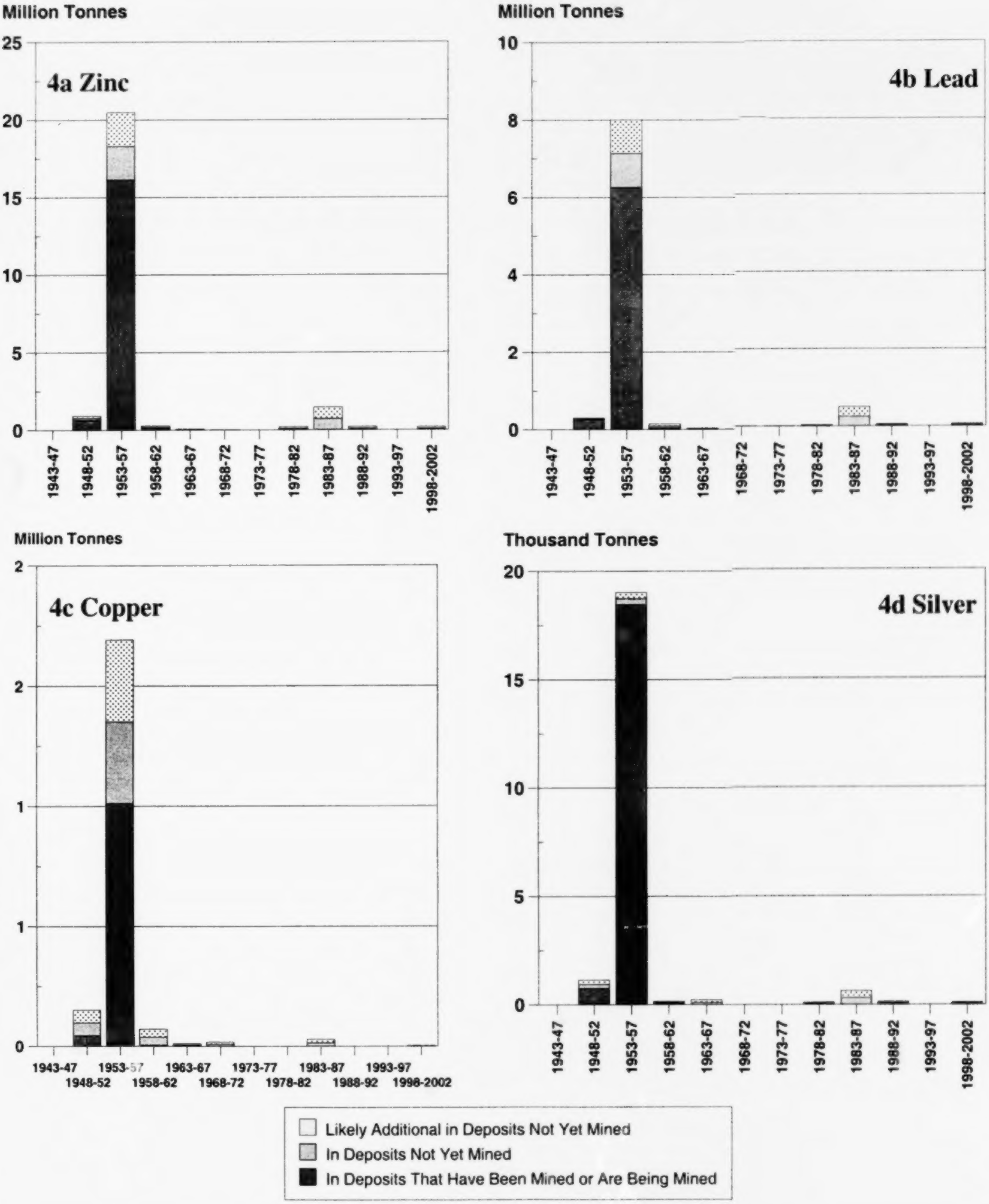


Figure 4. Metal content of massive sulphide deposits discovered in New Brunswick per-5 year period.

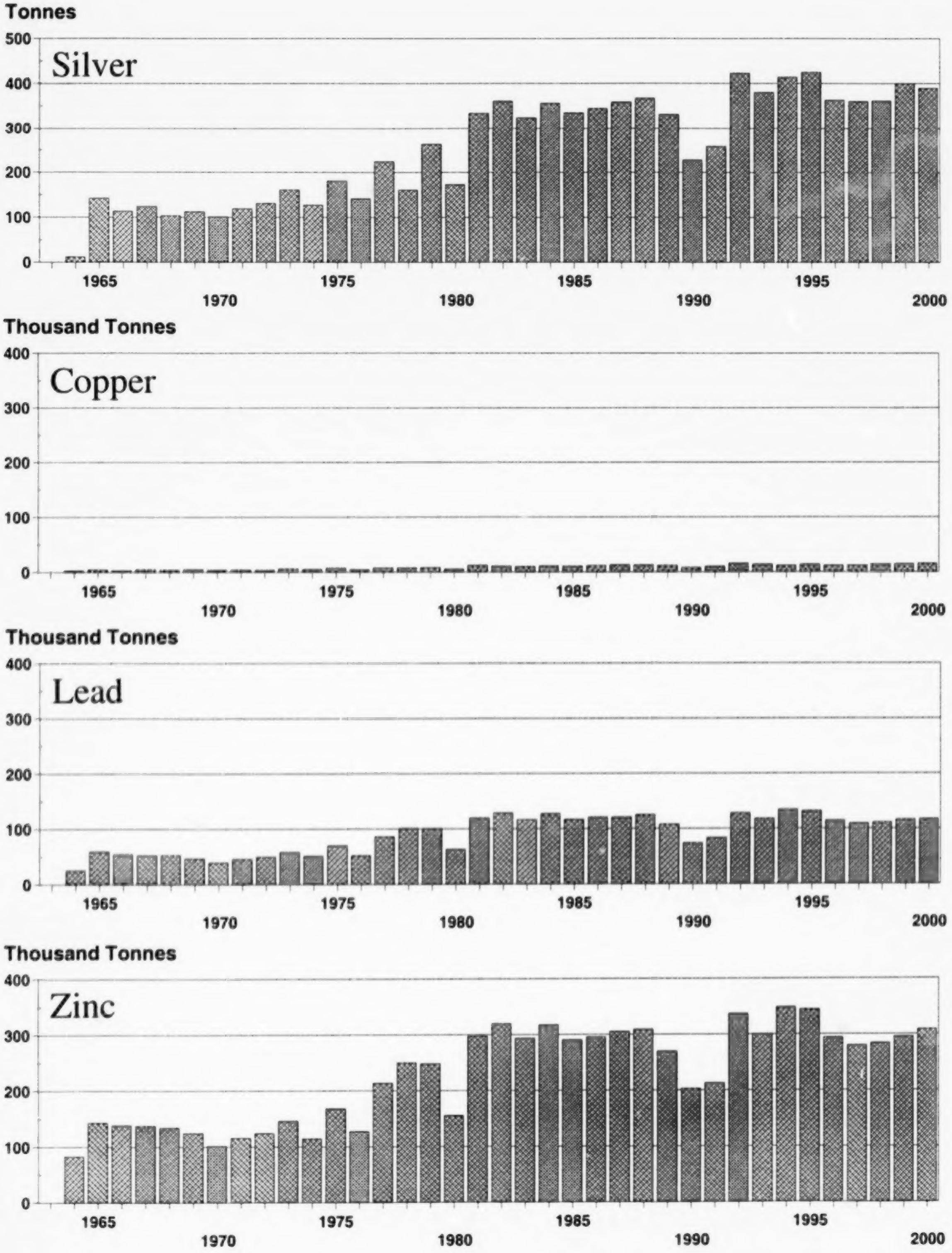


Figure 5. Brunswick #12 mine — metal content of ore milled.

scales are identical for each of zinc, lead and copper so that tonnages of metals can be readily compared. Note that the zinc content of the ore milled has significantly exceeded the lead content, and that both zinc and lead contents have considerably exceeded the copper content. Silver content of ore milled is also portrayed, but at a different scale than the other three metals.

Annual metal output from the Brunswick #6 mine (Figure 6 and Table 5) was much less than that from Brunswick #12. As at Brunswick #12, the zinc content of the ore exceeded the lead content, and both the zinc and lead contents greatly exceeded the copper content.

At the Heath Steele operation (Figure 7, Table 6), the copper content of the ore was considerably higher than that at the Brunswick #6 and Brunswick #12 mines. Heath Steele ore was somewhat unusual, in that it had a gold content of some 0.02 ounces of gold per short ton (about 0.7 g/t), whereas any gold that may have been contained in the Brunswick ores must have been insignificant. Heath Steele was closed between 1958 and 1962 because of metallurgical difficulties and low metal prices, and again between 1984 and 1989 and in 1993, owing to the low metal prices that prevailed in those years. Available production data for the Wedge mine, the Caribou mine, the Captain North Extension mine and the Murray Brook mine are presented in Tables 7, 8, 9 and 10, respectively.

METALLURGICAL RECOVERIES

The massive sulphide ores in the Bathurst District have not been significantly metamorphosed, so are very fine-grained, and can be described as fine-grained complex sulphide ores. Very fine grinding has been required to liberate individual sulphide mineral grains so as to permit production of saleable concentrates. A considerable portion of the silver content is contained in the galena, so that declining lead recoveries (Figure 8) have resulted in lower silver recoveries. Also, some of the silver is presumably associated with the iron sulphide minerals that have been deliberately rejected during flotation. Therefore, it has not been possible to recover a high proportion of that silver in any of the metal concentrates produced.

In processing ore to yield metal concentrates, it is not sufficient to have a particular metal report to just any concentrate. Metals are recoverable and paid for only if they are recovered in specific concentrates from which they can actually be recovered at the smelting–refining stages. For example, precious metals contained in copper concentrates are recovered in the blister copper or copper anodes produced at copper smelters, but zinc and lead recovered in copper concentrates are neither recovered nor paid for by copper smelters. Most zinc plants are unable to recover any of the lead or precious metals contained in the zinc concentrates they process. Both copper and silver contained in lead concentrates are recovered at lead smelters, in the form of copper dross and silver dross. Most of the silver is paid for, but the copper is normally not paid for and may even constitute a penalty element. Zinc, lead and silver are paid for in the bulk zinc–lead concentrates treated at Imperial Process smelters, but the prices received tend to be lower than if the zinc and lead are recovered in separate zinc and lead concentrates.

Figure 8 indicates the average annual percentage recoveries of payable metals from the Brunswick Mining and Smelting ores. The available information begins with 1974, because information for earlier years is not readily available. Over the years, zinc recoveries increased at the Brunswick concentrator, from about 76% in 1974, to about 86%. For an orebody as large as Brunswick #12, the improvement in zinc recoveries has been about comparable to the discovery at Bathurst of an additional moderately large zinc deposit. Copper recoveries from ore at the Brunswick operation have increased from about 30% in the mid-1970s,

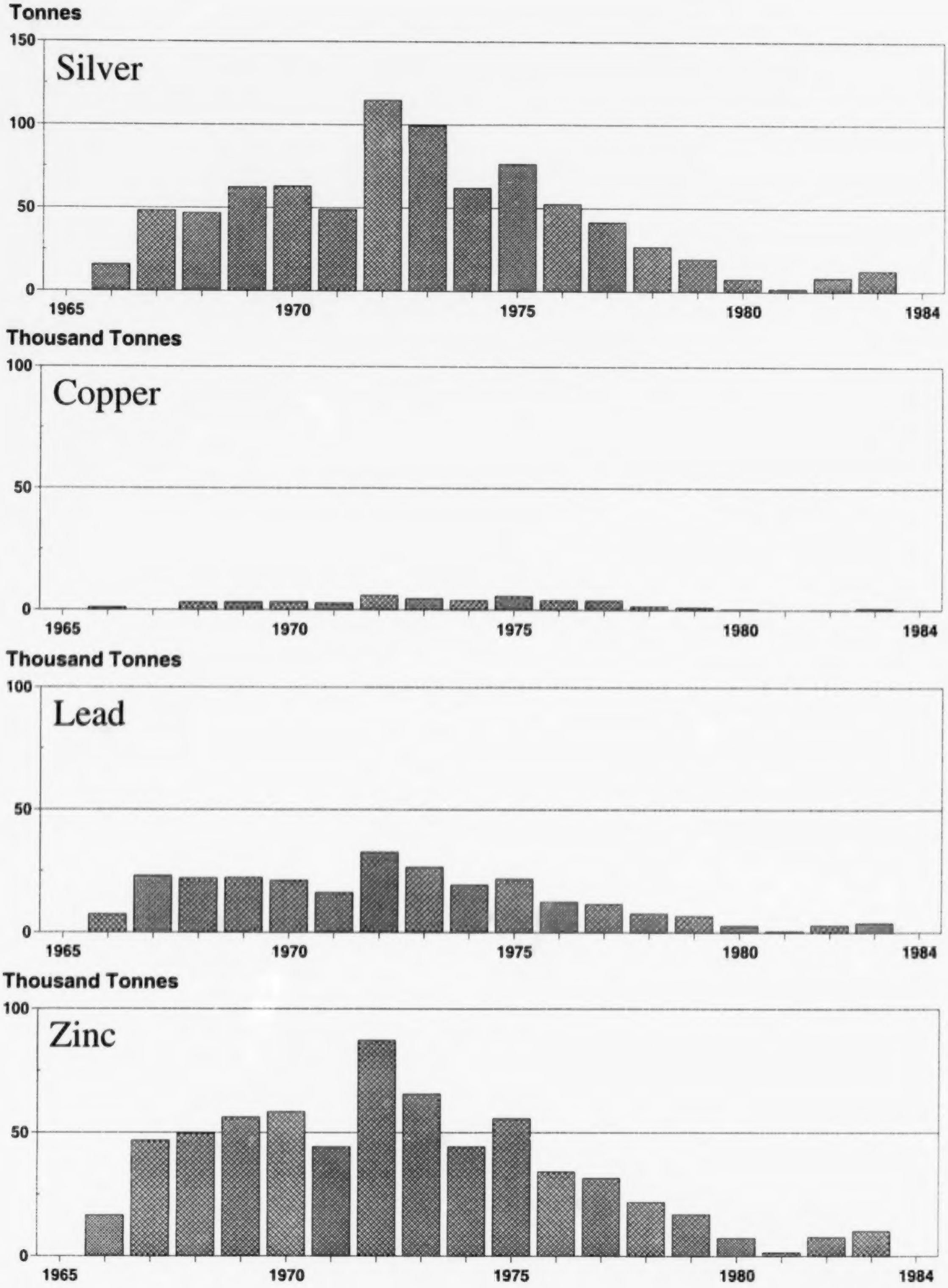


Figure 6. Brunswick #6 mine — metal content of ore milled.

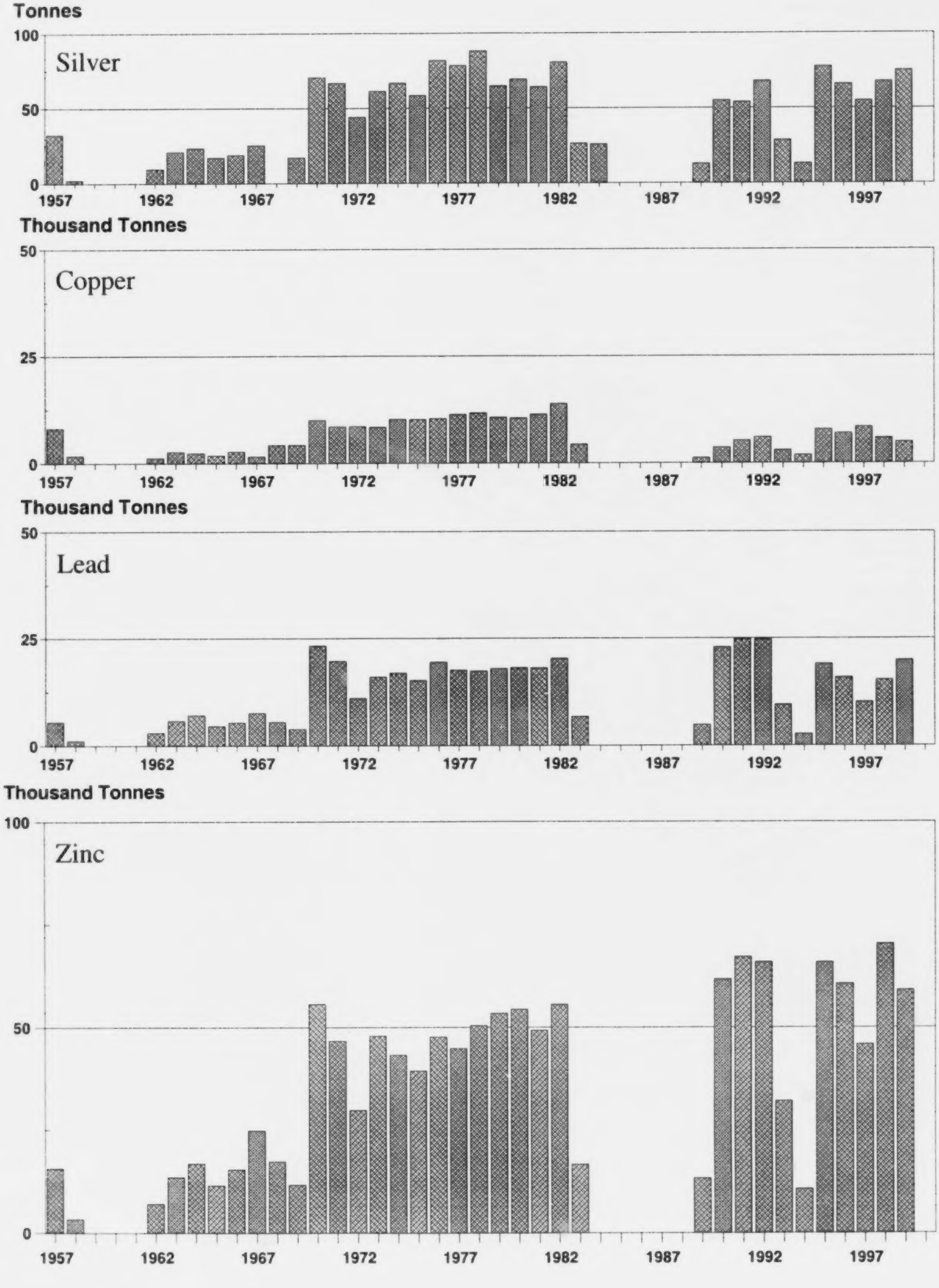


Figure 7. Heath Steele mines — metal content of ore milled.

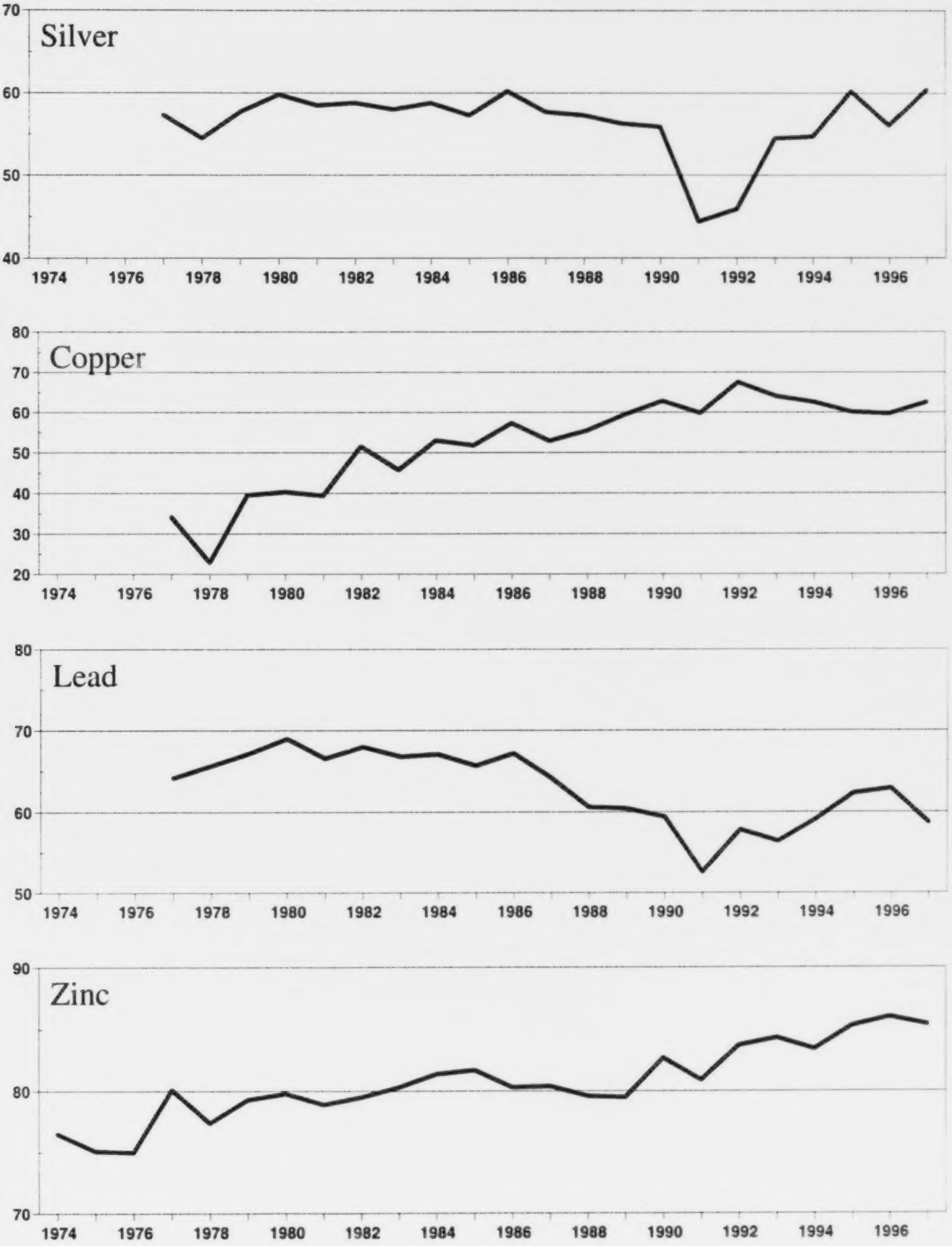


Figure 8. Brunswick Mining & Smelting — metallurgical recoveries — metal recovered as percentage of metal in ore milled.

to about 60% today. Silver recoveries haven't really improved, presumably because much of the silver is rejected to tailings with galena and iron sulphide minerals. There has been some decline in percentage recoveries of lead, most likely because of optimization of recoveries for higher-priced zinc.

Although not analysed here, the limited available information suggests that changes in recoveries at the Heath Steele operation haven't been much different than those at Brunswick. As is the case with the Brunswick concentrates, the zinc content of zinc concentrates, lead content of lead concentrates and copper content of copper concentrates were all quite low relative to contents of these metals in concentrates produced at mines elsewhere from non-complex ores. Ore from the Stratmat mine was mined and processed by Heath Steele Mines between 1989 and 1993, was less complex, so metallurgical recoveries from that ore were higher than those for ore from the other Heath Steele mines. The limited data available concerning metallurgical recoveries at the Caribou mine indicates that those metallurgical recoveries have been extremely poor, with more metal discarded in tailings than recovered as payable metal in concentrates. The copper, zinc and lead concentrates produced were so low grade that they must have been difficult to market. At some of the Canadian mines outside New Brunswick with non-complex sulphide ores, the grades of the ore mined have been not much higher than the grades of Caribou tailings.

Consider the McArthur River Sedex-type zinc–lead–copper deposit in Australia's Northern Territory, 227 000 000 t in size, discovered in 1952. This deposit is completely unmetamorphosed, with grain size only a few microns, and with the galena tending to occur as micron-sized inclusions in sphalerite. The McArthur River deposit has an added disadvantage, an arsenic content of 0.1 to 0.2%. When I examined photomicrographs of this mineralization in 1985, I concluded that the deposit wouldn't go into production for many years, if ever. But after remaining in limbo for some 40 years, the McArthur River deposit is now in production. It is to be hoped that the metallurgical difficulties at the Caribou operation can eventually be solved, as they appear to have been at McArthur River.

AVERAGE GRADES OF ORE MINED

Figures 9 and 10 depict at identical scales for zinc, lead and copper average annual zinc, lead, copper and silver grades of the ore that was produced from the Brunswick #12 and Brunswick #6 orebodies. Over the years, grades at Brunswick #12 have remained remarkably consistent.

Figure 11 depicts, also at identical scales for zinc, lead and copper, grades of ore mined at the Heath Steele operations. The anomalous silver grade in 1984 represents a brief period of leaching of near-surface supergene ore for gold and silver, at a time when mining of hypogene sulphide ore was suspended because of unfavourable market conditions.

METAL PRODUCTION FROM ALL MINES

Figures 12, 13, 14 and 15 indicate combined annual production of each of zinc, lead, copper and silver from all the massive zinc–lead–copper–silver sulphide deposits that have been mined in New Brunswick. Production from the Brunswick #12 deposit stands out because it so greatly exceeds that from any of the other mines.

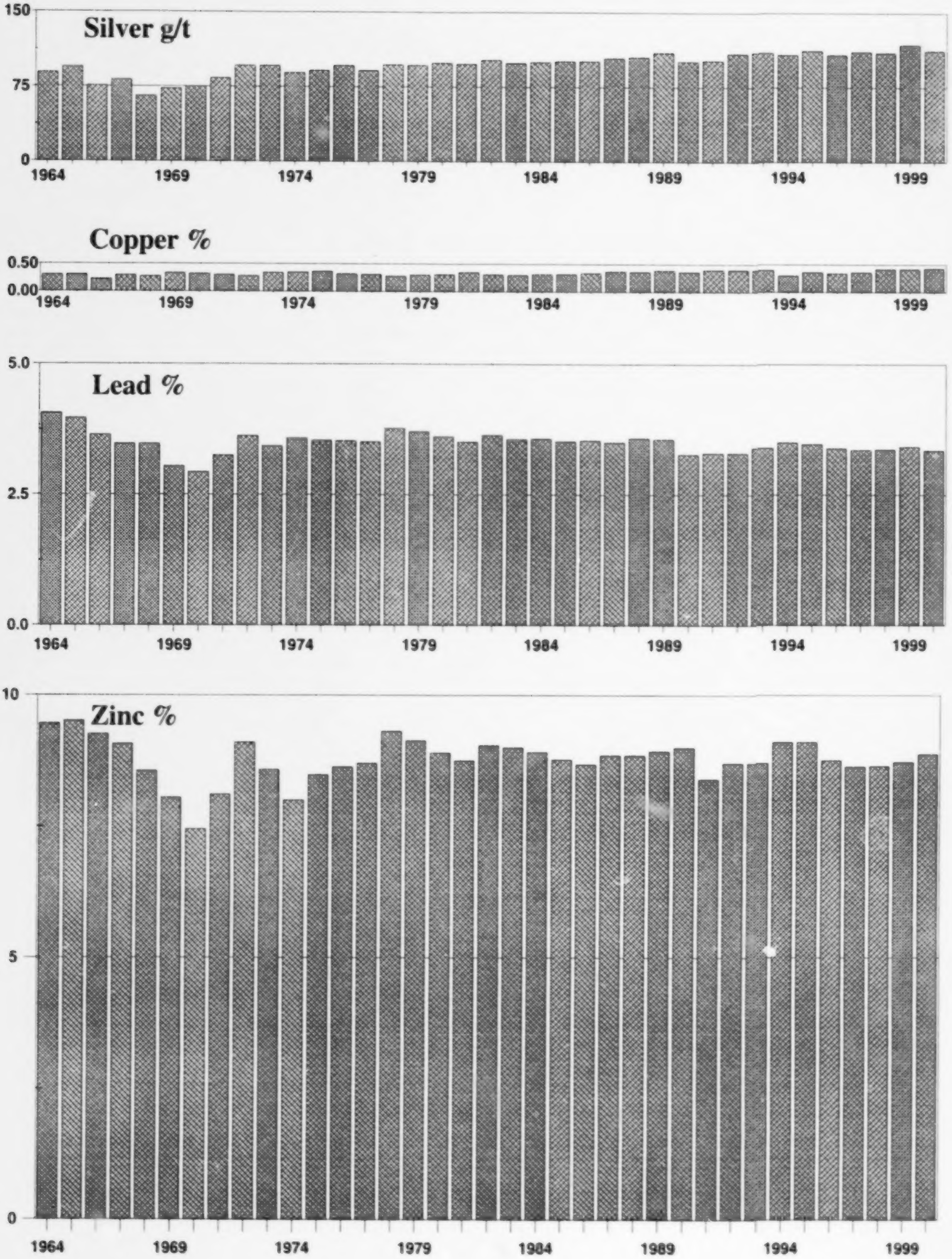


Figure 9. Brunswick #12 mine — annual grades of ore milled.

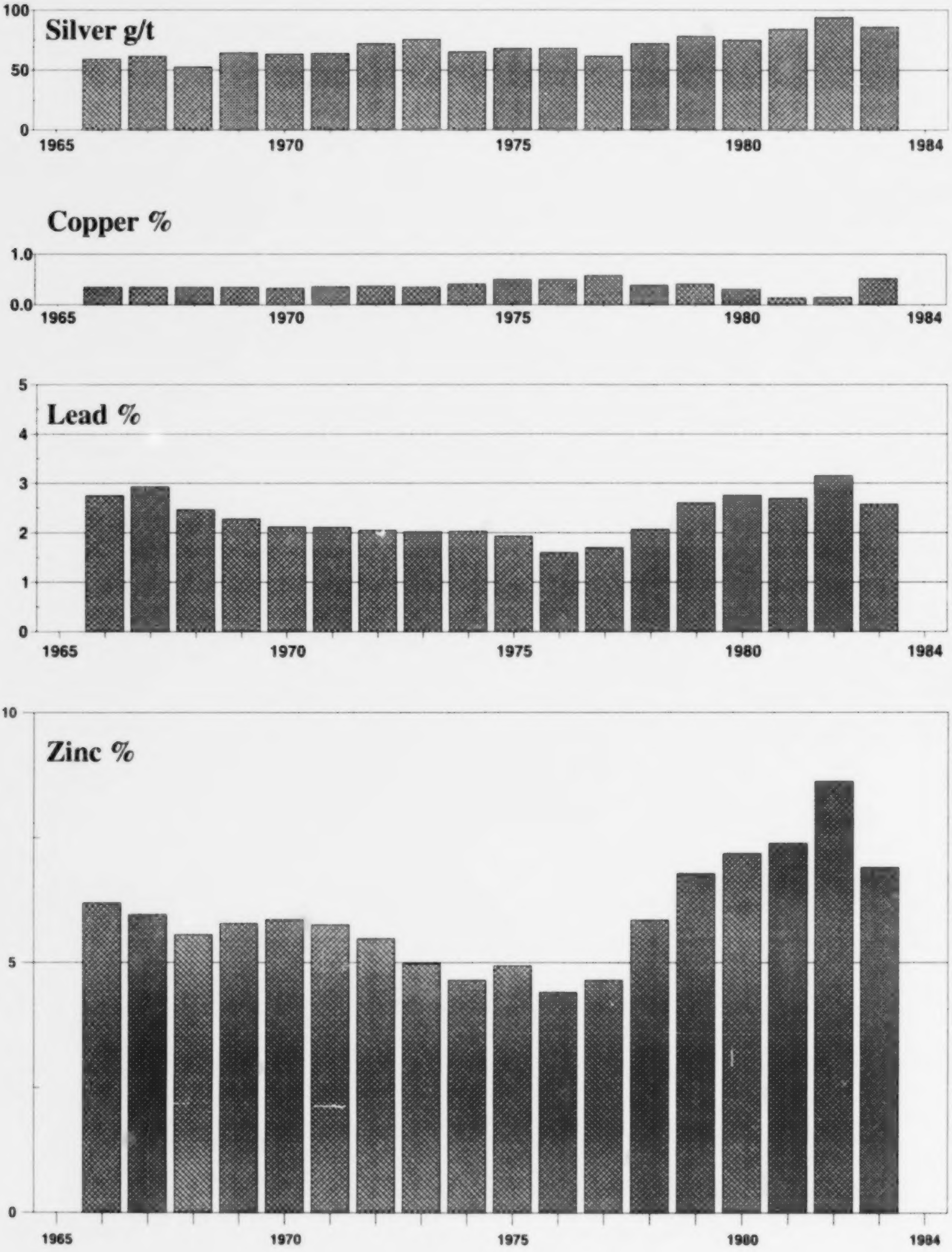


Figure 10. Brunswick #6 mine — annual grades of ore milled.

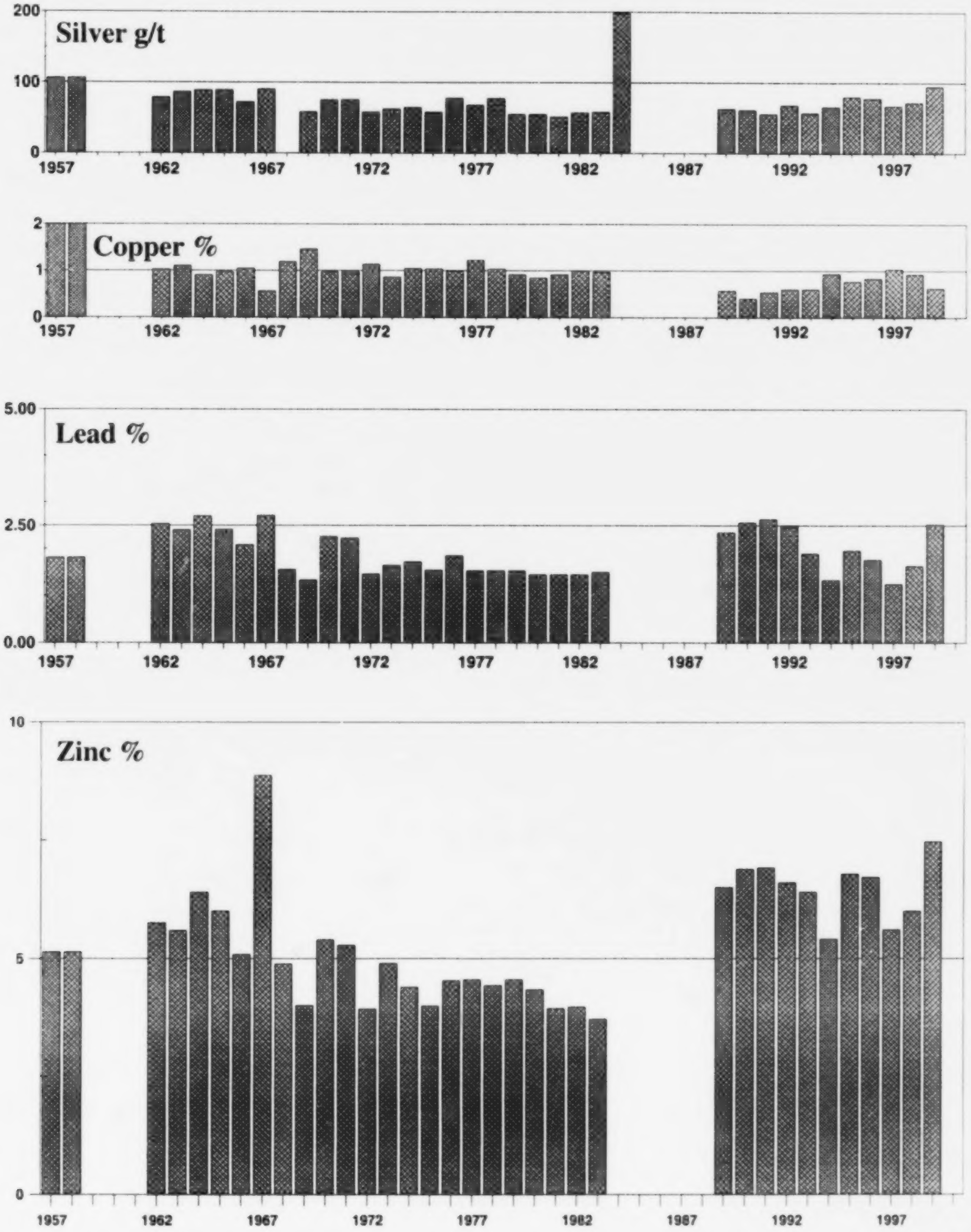
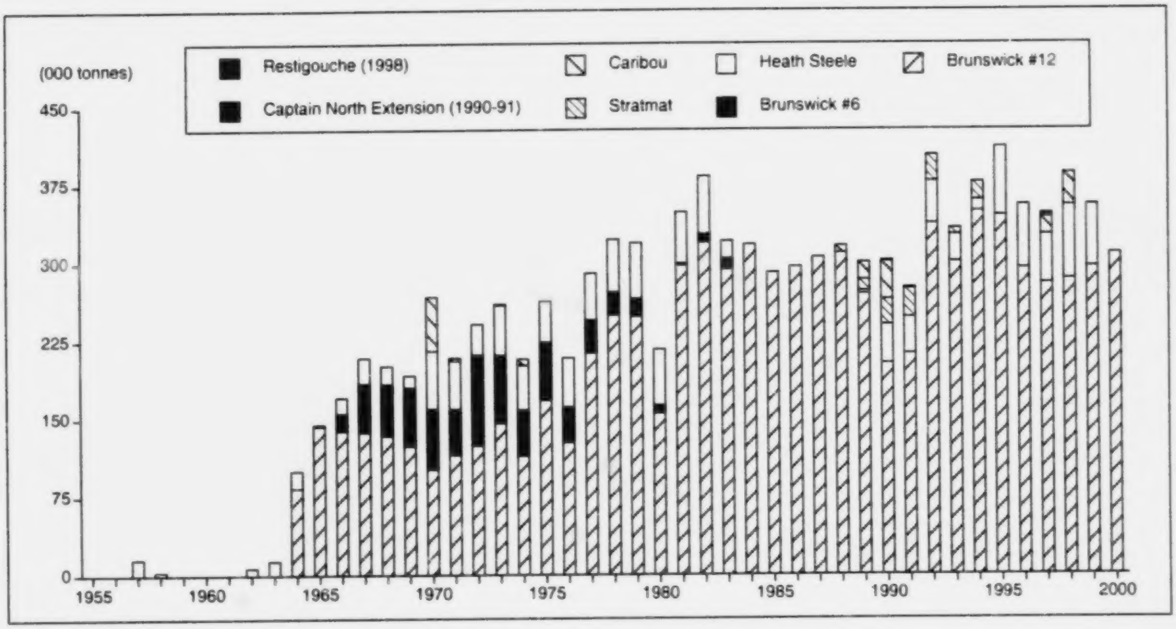
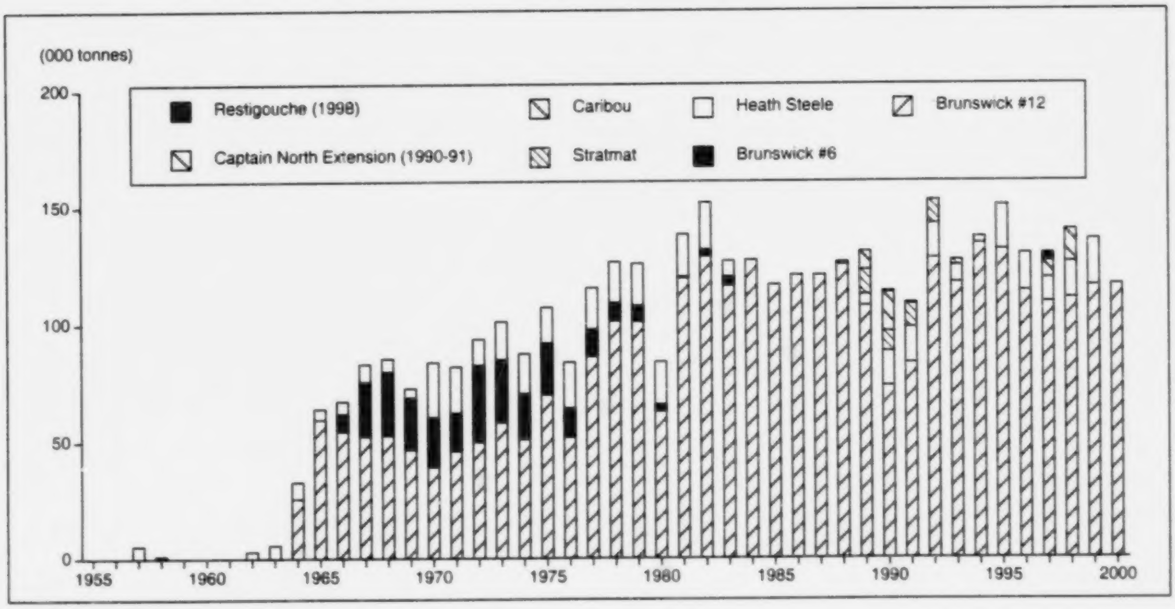


Figure 11. Health Steele mines — annual grades of ore milled.



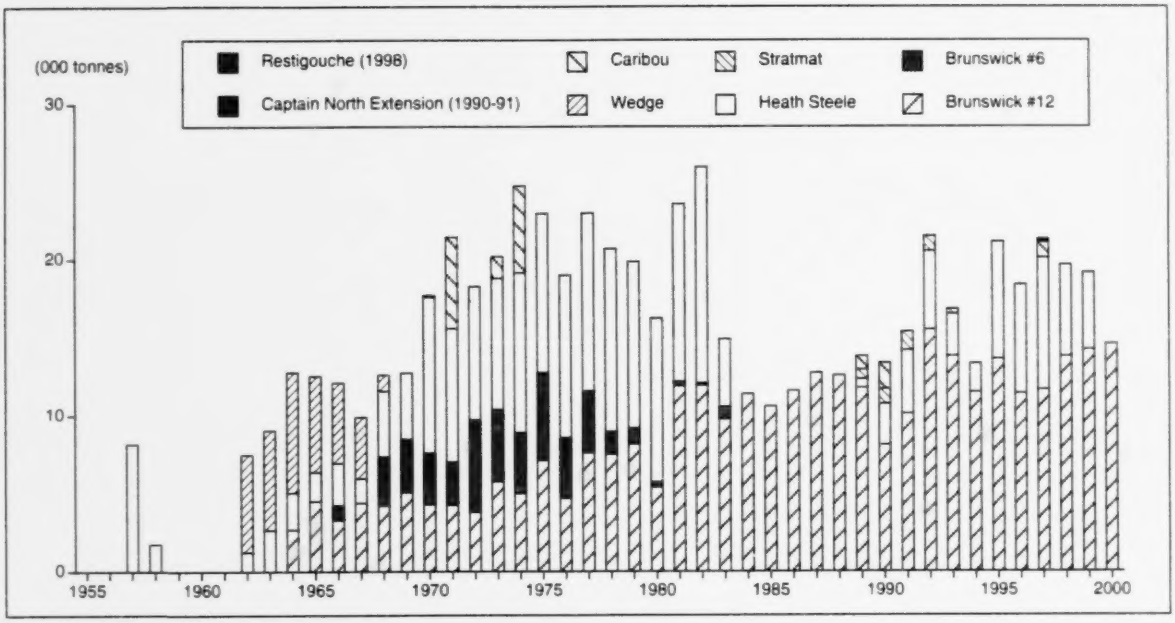
Source: Company annual reports, and questionnaires and other data received from companies.

Figure 12. Zinc content of ore mined from New Brunswick massive sulphide deposits, 1955–2000



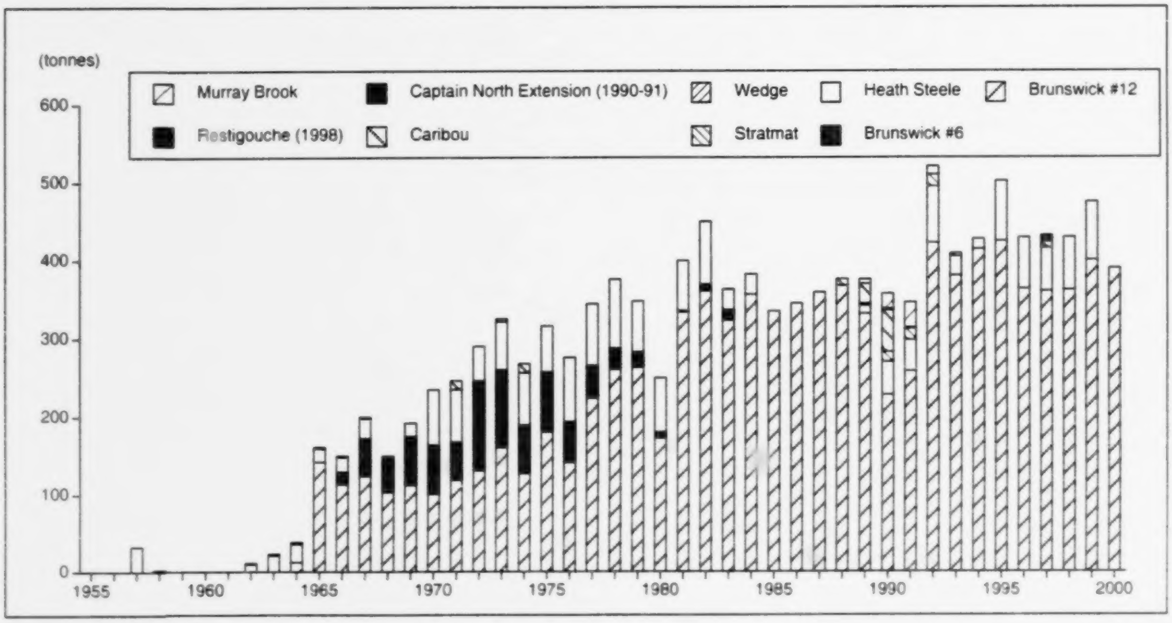
Source: Company annual reports, and questionnaires and other data received from companies.

Figure 13. Lead content of ore mined from New Brunswick massive sulphide deposits, 1955–2000



Source: Company annual reports, and questionnaires and other data received from companies.

Figure 14. Copper content of ore mined from New Brunswick massive sulphide deposits, 1955–2000



Source: Company annual reports, and questionnaires and other data received from companies.

Figure 15. Silver content of ore mined from New Brunswick massive sulphide deposits, 1955–2000

METAL CONTAINED IN ORE RESERVES

Figure 16 depicts available data concerning zinc, lead, copper and silver contents of ore reserves for the Brunswick Mining and Smelting operations. Reserves began to decline about 1986, when underground exploration had more-or-less outlined the limits of the Brunswick #12 orebody.

There was a sharp decline in copper reserves in 1979. The explanation is that some 13 000 000 t of what had, for many years, been called copper ore was dropped from ore reserves.

Figure 17 portrays the available data for the contents of zinc, lead, copper, silver and gold in the ore reserves at the Heath Steele operation. With the Heath Steele mine now closed, with no hope of reopening, reserves are now zero. But, as you can see in the figure, Noranda had a substantial additional mineral inventory in the general vicinity of its Heath Steele operation that has not been mined. The grades of this 10 000 000 or more tonnes of mineralized material are similar to the grades of the ore that has been mined, but this tonnage would appear to have been uneconomic under cost/price conditions that existed during at least much of the life of the operation. Almost 8 000 000 t of this are in the Halfmile Lake deposit. With the Heath Steele mine now closed and the concentrator removed from the site, the production economics of the unmined resources is much worse, so that with the exception of the Halfmile Lake deposit, they are unlikely to ever be mined.

THE FUTURE

What is the future of mining of massive sulphide ores in New Brunswick? In 2001, Brunswick #12 is the only mine remaining in production. The limits of the orebody appear to have been defined, with little, if any, potential for additional ore. Remaining ore reserves will be depleted by about 2010, with production expected to decline after 2007. Metal prices in the coming years could have a significant effect on the actual life of the mine. If they are low, final mine closure could come before 2010.

For many years, some 13 000 000 t of copper zone mineralization, which contains copper, zinc, lead and silver, were included in Brunswick #12 ore reserves, but were subsequently dropped from ore reserves in 1979. I have no knowledge of whether this material is potentially recoverable if metal prices were appropriate near the end of the mine-life, but as none of it was mined during periods of much higher than current copper prices, this possibility seems unlikely. Considerable unmined mineralized resource tonnages exist at the Caribou mine, and much smaller tonnages at the Restigouche mine and at other small massive sulphide deposits in the Bathurst District. The owner of the Caribou mine has stated that metallurgical recoveries can be improved, but that higher zinc prices will be required. It seems highly questionable that zinc prices will be higher in the long run than those that have prevailed in recent years. Therefore, any future production from the Caribou mine is likely to be sporadic at best.

The Halfmile Lake deposit, reported to contain resources of 7 780 000 t averaging 10.51% zinc, 3.66% lead, 0.09% copper and 44 g/t silver appears to offer attractive grades. As most massive sulphide deposits turn out to yield more ore than they were believed to have when mining began, the Halfmile Lake deposit may well turn out to be larger. However, Noranda is of the opinion that a zinc price of US$0.60 per pound will be required to make the deposit viable, and a sustained zinc price this high seems highly unlikely in the foreseeable future.

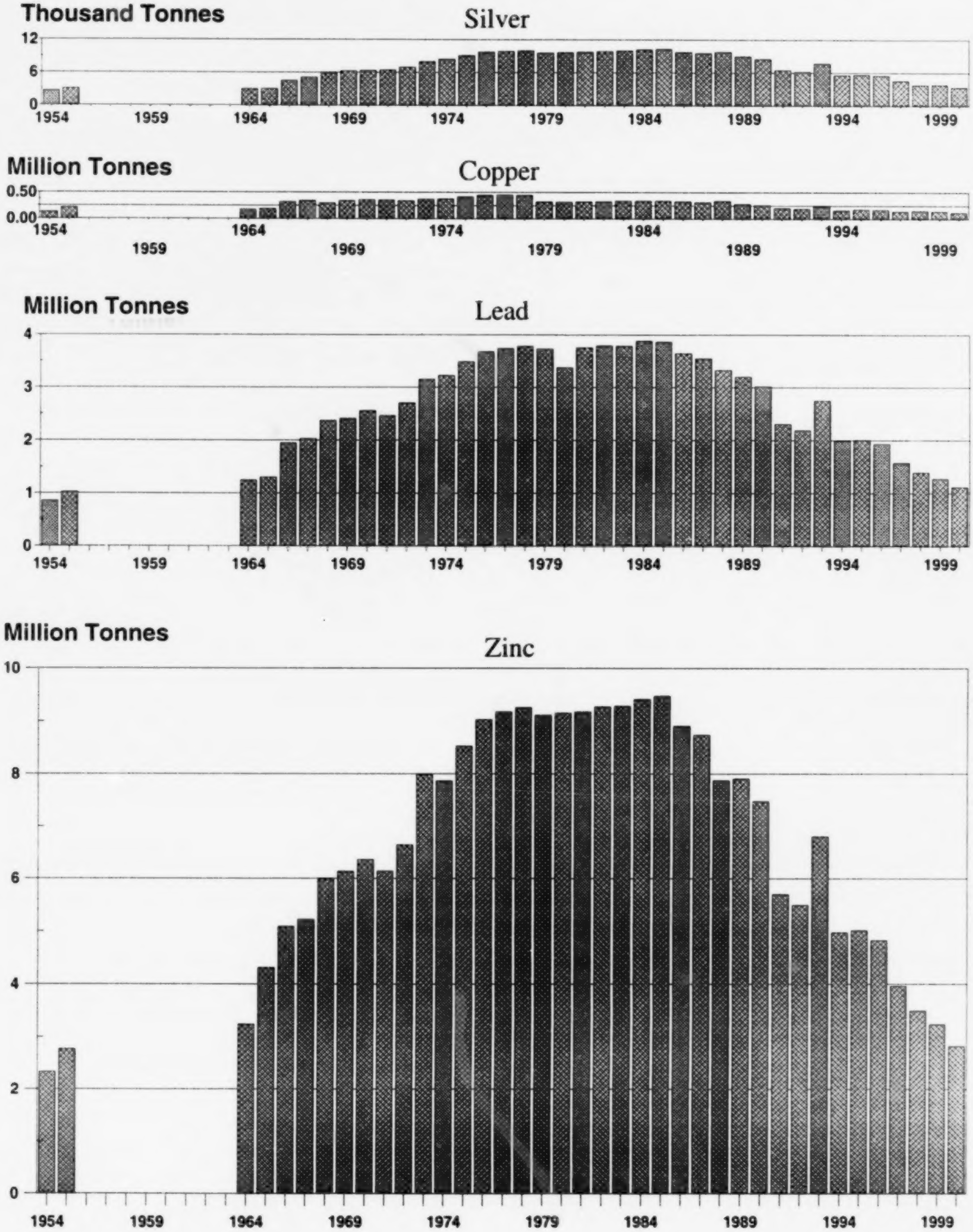


Figure 16. Brunswick Mining and Smelting — metal content of ore reserves on December 31.

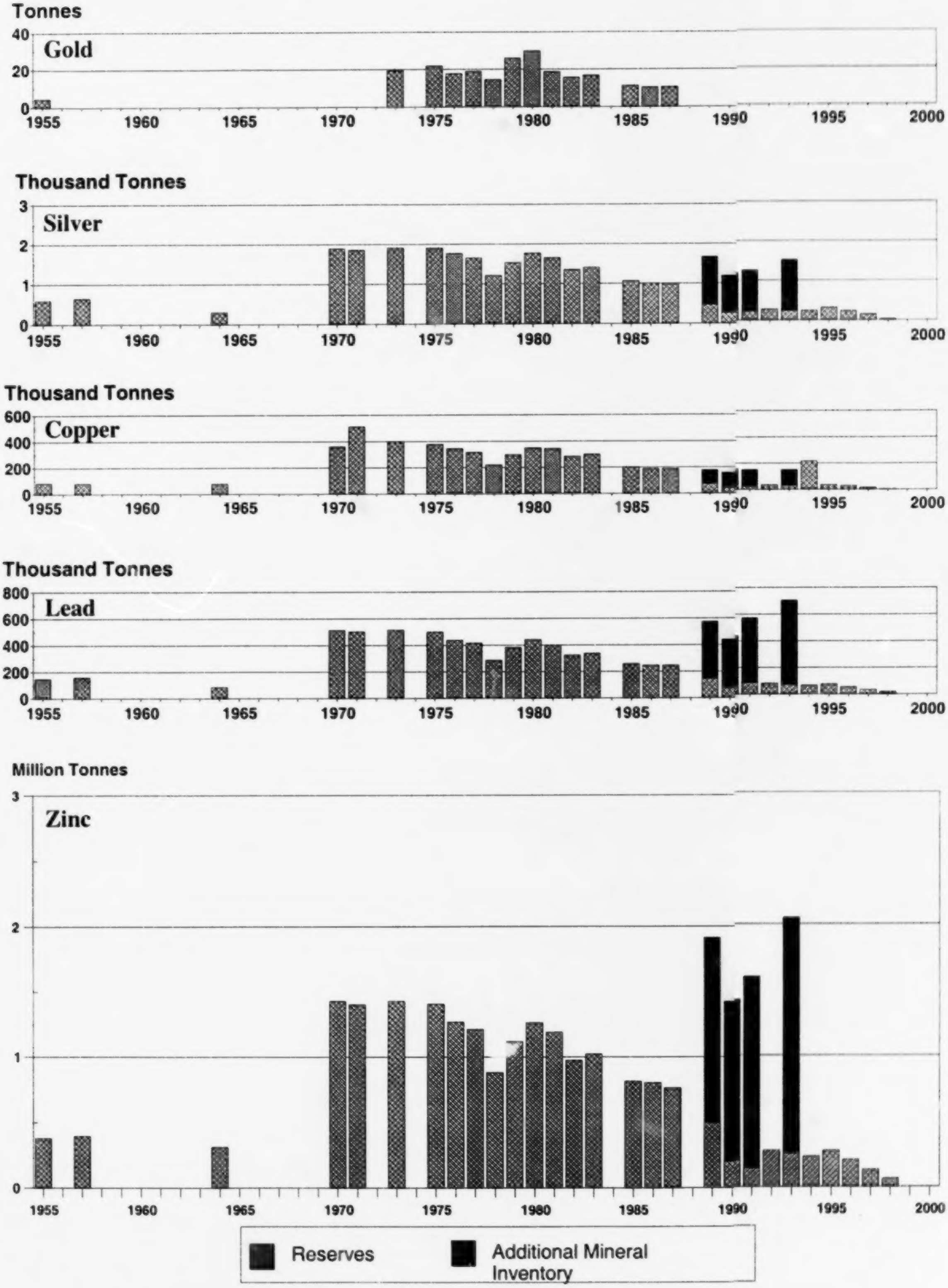


Figure 17. Heath Steele mines — metal content of ore reserves on December 31.

None of the various other massive sulphide deposits that have been discovered in New Brunswick appear to have tonnages and grades that are likely to be economically viable in the foreseeable future.

It is clear that additional ore deposits must be discovered if base metal mining is to continue in New Brunswick. The fact that massive sulphide deposits still continue to be discovered in the Bathurst District offers some encouragement. It is to be hoped that one of the deposits discovered in the future will be a large one. However, the general experience in mining districts worldwide has been that the largest orebodies tend to be discovered first, with a subsequent trend to the discovery of smaller deposits, at higher discovery costs.

Recall that the five large massive sulphide deposits (Figure 3, Figure 4) that have been found in the Bathurst District were all discovered over a five- or six-year period in the mid-1950s. Also recall that exploration expenditures in New Brunswick were relatively low in most of the years from 1958 to the mid-1970s (Figure 1). Over the 25 years, 1975–1999 inclusive, a total of $210 000 000 (year 2000 dollars) appears to have been spent on exploration for base metals in New Brunswick. Not all of this amount was spent in the Bathurst District. The question is, how many large base-metal deposits can we realistically expect to have discovered for $210 000 000?

In recent years, the cost of finding a large orebody in Canada has probably averaged somewhere between $110 000 000 and $165 000 000, expressed in year 2000 dollars. How to calculate average per deposit discovery costs in Canada is tricky, because many more small ore bodies are discovered than large ones. One could simply divide total exploration expenditures in Canada by the total number of deposits of all sizes discovered, to obtain an average discovery cost per orebody that is much lower than $110 000 000. To calculate the $110 000 000 to $165 000 000 average discovery cost for a large orebody, the author counted not only large deposits, but added numbers of smaller orebodies together to approximately equal large discoveries. This is an average cost, and doesn't mean that as much as $110 000 000 must be spent to have an exploration success because some major discoveries are made for much less. Nor is an ore discovery guaranteed for each $110 000 000 to $165 000 000 of exploration expenditures. As some discoveries have cost much less than this, others have cost considerably more. So having spent a total of $210 000 000 (year 2000 dollars) in New Brunswick on exploration for base metal deposits over 25 years (1975 to 1999) with no notable success does not necessarily indicate that possibilities have been exhausted for a major new ore discovery in the Bathurst District. There is a possibility that concealed, and perhaps deep, orebodies still remain to be discovered. Evolving exploration techniques and technology and new geological, geochemical and geophysical information may eventually provide the clues needed to make additional discoveries.

Brunswick #12 is an outstanding ore deposit, which contained some 150 000 000 t of mineable ore and another 20 000 000 t or more of mineralization for which mining is not currently planned. In the 150 years of mineral exploration in Canada, only two zinc–lead–silver deposit discoveries have been made in Canada that were larger than Brunswick #12. These are Cominco's Sullivan mine in British Columbia and the two or more Howards Pass zinc–lead deposits on the Yukon–Northwest Territories boundary. If copper–zinc deposits are also taken into account, the Kidd Creek orebody in Ontario is another volcanogenic massive sulphide deposit comparable to or larger in size than Brunswick #12. But if the total ore tonnage discovered in the entire Bathurst District is counted, in Canada only the Howards Pass deposit(s) contains a larger mineralized tonnage than does the Bathurst District. Bathurst is not only one of Canada's largest zinc–lead–copper–silver districts, but has also been one of the world's most important mining areas for these metals.

With the potential rewards that could result from a large, new massive sulphide discovery, the Bathurst District likely warrants continued exploration for some time yet.

Table 1. Prospecting Expenditures in New Brunswick by Senior Companies, Junior Companies and All Companies, 1946–1966

----- Prospecting Expenditures In Dollars of the year ----				--------- Prospecting Expenditures In 2000 Dollars ---------			
Year	By Senior Companies	By Junior Companies	By All Companies	GDP Deflator Series 1992 = 100	By Senior Companies	By Junior Companies	By All Companies
1946	298	0	298	11.1	3 030	0	3 030
1947	52 258	20	52 278	11.8	499 000	200	499 000
1948	6 591	0	6 591	13.3	55 900	0	55 900
1949	2 625	5 176	7 801	13.8	21 400	42 300	63 700
1950	904	899	1 803	14.1	7 230	7 190	14 420
1951	70 138	10 386	80,524	15.8	500 300	74 100	574 400
1952	90 818	41	90 859	16.4	624 100	300	624 400
1953	838 045	2 028 106	2 866 151	16.4	5 760 000	13 940 000	19 700 000
1954	1 776 455	17 471 161	3 523 616	16.6	12 100 000	11 900 000	24 000 000
1955	1 320 970	1 138 132	2 459 102	16.8	8 860 000	7 640 000	16 500 000
1956	2 899 331	1 014 537	3 913 768	17.4	18 800 000	6 600 000	25 400 000
1957	1 738 658	395 227	2 133 885	17.8	11 000 000	2 500 000	13 500 000
1958	392 650	123 526	516 176	18.0	2 460 000	770 000	3 230 000
1959	613 861	101 718	715 579	18.4	3 760 000	623 000	4 383 000
1960	1 455 231	131 645	1 586 876	18.6	8 820 000	800 000	9 620 000
1961	491 431	286 218	777 649	18.7	2 960 000	1 730 000	4 690 000
1962	617 817	43 147	660 964	19.0	3 660 000	256 000	3 916 000
1963	344 014	377 162	721 176	19.4	1 998 000	2 191 000	4 189 000
1964[1]	408 130	406 336	814 466	19.9	2 311 000	2 301 000	4 612 000
1965[1]	750 696	414 659	1 165 355	20.6	4 107 000	2 269 000	6 376 000
1966[1]	1 140 564	679 915	1 820 479	21.7	5 924 000	3 531 000	9 455 000

Note: [1] Prospecting expenditures for 1964–1966 were not compiled in this form by Statistics Canada. These data were compiled by the author from microfilm copies of the original completed questionnaires returned to Statistics Canada by companies.

Table 2. Mineral Exploration Expenditures in New Brunswick , 1967–2000

	Current Dollars (Dollars of the Year)			Year 2000 Dollars			
Year	By Senior Companies	By Junior Companies	By All Companies	GDP Deflator Series 1992 = 100	By Senior Companies	By Junior Companies	By All Companies
1967	n.a.	n.a.	2 137 600	22.6	n.a.	n.a.	10 660 000
1968	n.a.	n.a.	3 456 000	23.5	n.a.	n.a.	16 575 000
1969	2 496 400	565 200	3 061 600	24.5	11 480 000	2 600 000	14 080 000
1970	n.a.	n.a.	4 224 000	25.7	n.a.	n.a.	18 520 000
1971	908 900	1 241 500	2 151 400	26.6	3 851 000	5 260 000	9 111 000
1972	n.a.	n.a.	n.a.	28.2	n.a.	n.a.	n.a.
1973	943 000	967 200	1 910 200	30.8	3 457 000	3 550 000	7 007 000
1974	n.a.	n.a.	n.a.	35.4	n.a.	n.a.	n.a.
1975	4 976 300	827 400	5 803 700	39.0	14 380 000	2 390 000	16 770 000
1976	n.a.	n.a.	n.a.	42.6	n.a.	n.a.	n.a.
1977	5 133 200	102 600	5 235 800	45.5	12 710 000	254 000	1 296 400
1978	n.a.	n.a.	n.a.	48.5	n.a.	n.a.	n.a.
1979	9 178 100	32 600	9 210 700	53.1	19 480 000	69 000	19 549 000
1980	n.a.	n.a.	n.a.	58.9	n.a.	n.a.	n.a.
1981	12 262 800	85 500	12 348 300	65.4	21 130 000	147 000	21 277 000
1982	n.a.	n.a.	n.a.	71.0	n.a.	n.a.	n.a.
1983	12 452 000	541 500	12 993 500	74.8	18 770 000	816 000	19 586 000
1984	11 317 900	1 658 000	12 975 900	77.3	16 500 000	2 420 000	18 920 000
1985	12 210 600	1 511 200	13 721 800	79.2	17 380 000	2 150 000	19 530 000
1986	11 001 800	1 807 300	12 809 100	81.4	15 240 000	2 500 000	17 740 000
1987	9 923 400	928 600	10 852 000	85.3	13 110 000	1 230 000	14 340 000
1988	11 852 000	4 525 300	16 377 300	89.2	18 900 000	7 220 000	26 110 000
1989	7 977 000	5 613 000	13 590 000	93.3	9 640 000	6 780 000	16 420 000
1990	13 009 000	3 497 000	16 506 000	96.1	15 300 000	4 100 000	19 400 000
1991	14 882 000	923 000	15 805 000	98.7	17 000 000	1 050 000	18 050 000
1992	11 837 000	370 000	12 207 000	100.0	13 300 000	13 800 000	27 100 000
1993	10 392 000	702 000	11 094 000	101.5	11 540 000	780 000	12 320 000
1994	9 119 000	900 000	10 019 000	102.6	10 010 000	998 000	11 010 000
1995	10 180 000	2 537 000	12 717 000	104.9	10 930 000	2 730 000	13 660 000
1996	10 202 000	4 589 000	14 791 000	106.7	10 770 000	4 846 000	15 616 000
1997	7 769 000	5 399 000	13 368 000	107.7	8 126 000	5 647 000	13 773 000
1998	7 798 000	2 313 000	10 111 000	107.1	8 203 000	2 433 000	10 636 000
1999	8 713 000	1 400 000	10 113 000	108.8	9 027 000	1 450 000	10 477 000
2000	10 267 000	1 858 000	12 125 000	112.7	10 270 000	1 858 000	12 122 000

Notes: Source is Natural Resources Canada. Overhead exploration costs included.

Exploration totals for years 1997–2000 inclusive are "Exploration and Deposit Appraisal," which in addition to the exploration expenditures reported for years prior to 1997, may also include costs of engineering studies, feasibility studies and environmental studies, which were not included in 1996 and earlier years.

From 1971 to 1983, Statistics Canada did not publish exploration expenditures for New Brunswick alone, but included such expenditures in a total for "Atlantic Provinces." For odd numbered years, 1971–1983 inclusive, the author compiled New Brunswick totals (General Exploration plus On-Property Exploration) using the actual questionnaires completed by companies and returned to Statistics Canada.

Table 3. Mineral Exploration Expenditures[1] in New Brunswick for the Base Metals

Current Dollars (Dollars of the Year)			Year 2000 Dollars		
Year	Total[2]	Base Metals[3]	GDP Deflator Series 1992 = 100	Total	Base Metals
1975	5 803 700	2 886 200	39.0	16 771 000	8 340 000
1976	n.a.	n.a.	42.6	n.a.	n.a.
1977	5 235 000	2 995 000	45.5	12 969 000	7 418 000
1978	n.a.	n.a.	48.5	n.a.	n.a.
1979	9 210 700	1 410 000	53.1	19 549 000	2 993 000
1980	n.a.	n.a.	58.9	n.a.	n.a .
1981	12 348 300	7 744 000	65.4	21 279 000	13 345 000
1982	n.a.	n.a.	71.0	n.a.	n.a.
1983	12 993 500	2 548 000	74.8	19 577 000	3 839 000
1984	12 975 900	n.a.	77.3	18 918 000	n.a.
1985	13 721 800	4 778 000	79.2	19 526 000	6 799 000
1986	12 809 100	2 656 000	81.4	17 734 000	3 677 000
1987	10 852 000	4 378 000	85.3	14 338,000	5 784 000
1988	16 377 300	6 264 000	89.2	20 692,000	7 914 000
1989	13 590 000	6 301 000	93.3	16 416 000	7 611 000
1990	16 506 000	9 502 000	96.1	19 357 000	11 143 000
1991	15 805 000	12 503 000	98.7	18 047 000	14 276 000
1992	12 207 000	9 096 000	100.0	13 757 000	10 251 000
1993	11 094 000	8 034 000	101.5	12 318 000	8 921 000
1994	10 019 000	842 300	102.6	11 005 000	9 252 000
1995	12 717 000	8 944 000	104.9	13 663 000	9 609 000
1996	14 791 000	11 973 000	106.7	15 623 000	12 646 000
1997	13 368 000	10 516 000	107.7	13 989 000	11 004 000
1998	10 111 000	7 739 000	107.1	10 640 000	8 144 000
1999	10 113 000	6 733 000	108.8	10 476 000	6 974 000
2000	12 125 000	7 761 000	112.7	12 125 000	7 761 000

Notes: Source is Natural Resources Canada.

[1] Exploration totals for years 1997–2000 inclusive are "Exploration and Deposit Appraisal," which, in addition to the exploration expenditures reported for years prior to 1997, may also include costs of engineering studies, feasibility studies and environmental studies, which were not included in 1996 and earlier years.

[2] From 1971 to 1983 inclusive, Statistics Canada did not publish exploration expenditures for New Brunswick alone but included such expenditures in a total for "Atlantic Provinces." For odd-numbered years 1971–1983 inclusive, the author compiled New Brunswick totals (General Exploration plus On-Property Exploration) using the actual questionnaires completed by companies and returned to Statistics Canada.

[3] Beginning in 1975, Statistics Canada questionnaires asked what commodities each company had been exploring for, but these data were not compiled. The author used the questionnaires returned to Statistics Canada to compile expenditures for base metals exploration for 1975, 1977, 1979, 1981 and 1983. Data for 1985 and subsequent years are from the Federal–Provincial Exploration Survey.

Table 4. Brunswick #12 Mine — Annual Ore Production

Year	Ore Milled (t)	Zn (%)	Pb (%)	Cu (%)	Ag (g/t)
1963	0	–	–	–	–
1964 [1]	876 828	9.46	4.06	0.30	89.2
1965	1 503 676	9.51	3.96	0.30	94.6
1966	1 497 905	9.26	3.64	0.22	75.8
1967	1 514 001	9.07	3.47	0.29	81.9
1968	1 564 408	8.56	3.47	0.27	65.8
1969	1 538 948	8.05	3.04	0.33	73.0
1970	1 343 903	7.45	2.93	0.32	75.1
1971	1 421 558	8.11	3.25	0.30	83.6
1972	1 365 676	9.10	3.62	0.28	96.0
1973	1 700 853	8.58	3.43	0.34	96.0
1974	1 428 749	8.00	3.58	0.35	89.1
1975	1 982 313	8.48	3.54	0.36	91.2
1976	1 473 268	8.63	3.53	0.32	96.0
1977	2 456 656	8.70	3.51	0.31	91.2
1978	2 685 715	9.31	3.77	0.28	97.0
1979	2 722 461	9.13	3.77	0.28	96.7
1980	1 746 000	8.90	3.61	0.31	99
1981	3 401 000	8.75	3.51	0.35	98
1982	3 534 750	9.04	3.64	0.31	102
1983	3 263 600	9.00	3.56	0.30	99
1984	3 560 200	8.91	3.57	0.32	100
1985	3 311 600	8.77	3.52	0.32	101
1986	3 408 600	8.68	3.54	0.34	101
1987	3 446 923	8.85	3.50	0.37	104
1988	3 493 940	8.85	3.58	0.36	105
1989	3 022 618	8.93	3.56	0.39	109.5
1990	2 255 000	9.00	3.27	0.36	101
1991	2 531 000	8.4	3.3	0.4	102
1992	3 874 000	8.7	3.3	0.4	109
1993	3 454 000	8.7	3.4	0.4	110
1994	3 833 000	9.1	3.5	0.3	108
1995	3 789 492	9.1	3.47	0.36	112
1996	3 360 688	8.75	3.39	0.34	108
1997	3 244 310	8.63	3.36	0.36	111
1998	3 286 000	8.64	3.37	0.42	110
1999	33 390 753	8.72	3.42	0.42	118
2000	3 476 737	8.87	3.35	0.42	112

Note: [1] Tonnages and silver grades for years 1964 to 1979 inclusive have been converted from short tons to metric tons and from ounces of silver/ton to grams/tonne.

Table 5. Brunswick #6 Mine — Annual Ore Production

Year	Ore Milled (t)	Zn % (%)	Pb % (%)	Cu % (%)	Ag g/t (%)
1965	0	–	–	–	–
1966[1]	268 300	6.19	2.75	0.35	59.0
1967	786 900	5.96	2.93	0.35	61.4
1968	892 920	5.56	2.47	0.35	52.5
1969	974 170	5.78	2.28	0.35	64.1
1970	998 500	5.86	2.12	0.33	63.1
1971	768 365	5.76	2.11	0.36	63.8
1972	1 593 160	5.48	2.05	0.37	72.0
1973	1 317 042	4.98	2.02	0.35	75.4
1974	953 460	4.65	2.03	0.41	65.1
1975	1 126 826	4.94	1.93	0.50	67.9
1976	773 998	4.41	1.60	0.50	67.9
1977	677 700	4.65	1.70	0.58	61.4
1978	372 585	5.85	2.07	0.39	72.0
1979	249 000	6.78	2.60	0.41	78.2
1980	102 000	7.18	2.75	0.31	75
1981	22 000	7.38	2.69	0.14	84
1982	98 750	8.62	3.15	0.15	94
1983	147 100	6.90	2.57	0.52	86
1984	0	–	–	–	–

Note: [1] The Brunswick # 6 mine produced from September 1966 until 1983. Production ceased when the orebody was exhausted. Tonnages and silver grades for years 1966 to 1979 inclusive have been converted from short tons to metric tons, and from ounces of silver/ton to grams/tonne.

Table 6. Heath Steele Operations — Annual Ore Production[1]

Year	Ore Milled (t)	Zn (%)	Pb (%)	Cu (%)	Ag (g/t)	Au (g/t)
1957[2]	304 677	5.14	1.81	2.68	105.9	n.a.
1958[2]	65 171	5.14	1.81	2.68	106.9	n.a.
1959	0	–	–	–	–	–
1960	0	–	–	–	–	–
1961	0	–	–	–	–	–
1962[3]	122 649	5.76	2.53	1.02	78.9	n.a.
1963	241 256	5.6	2.4	1.1	86.7	n.a.
1964	263 084	6.4	2.7	0.9	89.1	n.a.
1965	191 416	6.01	2.41	0.97	89.5	n.a.
1966	260 829	5.09	2.08	1.04	72.3	n.a.
1967	280 199	8.87	2.71	0.56	90.5	n.a.
1968	355 039	4.89	1.55	1.19	54	n.a.
1969	291 590	4.00	1.33	1.46	58.6	n.a.
1970	935 216	5.40	2.26	0.97	75.4	n.a.
1971	882 197	5.29	2.23	0.97	75.8	n.a.
1972	758 286	3.93	1.46	1.13	58.3	n.a.
1973	977 773	4.90	1.64	0.86	62.7	0.58
1974	984 744	4.39	1.72	1.04	64.8	0.62
1975	988 326	3.99	1.54	1.03	58.3	0.62
1976	1 052 568	4.53	1.85	0.99	77.8	0.62
1977	1 150 338	4.55	1.53	1.22	68.2	0.69
1978	1 137 767	4.43	1.53	1.03	77.5	0.89
1979	1 172 737	4.55	1.53	0.91	55.2	0.69
1980	1 252 406	4.34	1.45	0.84	55.2	1.03
1981	1 249 928	3.94	1.45	0.91	51.4	0.69
1982	1 399 078	3.97	1.45	0.99	57.6	0.82
1983	449 615	3.71	1.50	0.98	58.63	0.69
1984[4]	130 666	–	–	–	198.34	4.63
1985	0	–	–	–	–	–
1986	0	–	–	–	–	–
1987	0	–	–	–	–	–
1988	0	–	–	–	–	–
1989	203 482	6.50	2.35	0.57	63.19	–
1990	896 661	6.88	2.56	0.40	61.37	–
1991	970 688	6.91	2.63	0.54	55.65	–
1992	997 903	6.6	2.48	0.60	68.09	–
1993	502 000	6.40	1.90	0.60	57.02	–
1994	198 490	5.41	1.33	0.93	65.86	–
1995	970 325	6.78	1.96	0.77	79.89	–
1996	903 200	6.71	1.76	0.83	78.1	–
1997	817 384	5.61	1.25	1.03	67.3	–
1998	942 649	6.00	1.63	0.92	71.88	–
1999[5]	791 353	7.46	2.52	0.62	94.68	–
2000	0	–	–	–	–	–

Notes: n.a. Not available

[1] For years 1964–1977 and 1983–1996 there are many inexplicable discrepancies in the tonnages and grades listed here (source Heath Steele Mines Ltd) and those in the records of the New Brunswick Department of Natural Resources and Energy, which came from Heath Steele Mines records.

[2] Mine produced from February 1957 to March 1958. Ore grades for 1957 and 1958 are available only for the two year's production combined.

[3] Production resumed January 1962.

[4] Production in 1984 was of near-surface gossan material.

[5] Mine permanently closed October 1999

Table 7. Wedge Mine — Annual Ore Production and Concentrates Produced

Year	Ore Milled (t)	Concentrates Produced			
		(t)	Cu (%)	Au (g/t)	Ag (g/t)
1962	203 140	29 443	19.20	0.31	48.3
1963	238 600	30 492	19.00	0.34	61.7
1964	255 514	36 367	19.35	0.46	67.4
1965	246 436	29 486	19.00	0.41	60.0
1966	244 300	25 951	18.06	0.41	68.6
1967	233 164	19 991	17.82	0.41	83.1
1968	82 591	5 586	16.6	n.a.	n.a.
1969	0	–	–	–	–

Table 8. Caribou Mine — Annual Ore Production[1]

Year	Ore Milled (t)	Zn (%)	Pb(%)	Cu (%)	Ag (g/t)	Au (g/t)
1970[2]	2 720	n.a.	n.a.	n.a.	n.a.	n.a.
1971[3]	140 609	1.90	n.a.	3.83	n.a.	n.a.
1972	0	–	–	–	–	–
1973[4]	40 823	3.0	n.a.	3.4	n.a.	n.a.
1974[5]	148 263	3.95	1.86	3.76	78.8	0.7
1988[6]	37 530	7.18	3.04	n.a.	84.99	n.a.
1989[7]	258 548	6.44	3.05	0.33	96.69	1.41
1990[8]	551 459	6.49	3.00	0.36	101.14	1.37
1997[9]	322 827	6.3	3.3	n.a.	102	n.a.
1998[10]	494 449	6.3	3.8	n.a.	105	n.a.
1999	0	–	–	–	–	–

Notes: Sources are Natural Resources Canada records and company annual reports.

[1] Includes production from the Restigouche deposit in 1997 and 1998.

[2] Mill opened on a tune-up basis late in 1970.

[3] Production suspended November 1971 due to metallurgical difficulties in producing marketable concentrates.

[4] Re-opened in mid-September 1973.

[5] Copper ore exhausted in November 1974.

[6] Re-opened in August 1988.

[7] Closed in August 1989.

[8] Re-opened in March 1990 and closed in October 1990 "due to unfavourable market conditions."

[9] Milling commenced in July 1997.

[10] Mine and mill shut down in August 1998.

Table 9. Captain North Extension Mine — Annual Ore Production

Year	Ore milled (t)	Zn (%)	Pb (%)	Cu (%)	Ag (g/t)
1990	11 104[1]	11.40	5.29	0.17	163.89
1991	14 559[2]	11.39	4.58	–	144.00
1992	13 619[2]	7.65	2.82	–	97.89
1993[3]	0	–	–	–	–

Notes: Source is company annual reports.

[1] This was a bulk sample mined in August and milled at Heath Steele from September 4–9, 1990.

[2] The ore milled at Heath Steele in 1991 and 1992 was all mined in the second half of 1991.

[3] Heath Steele was unwilling to accept any further custom ore so that there was no further production from the CNE deposit.

Table 10. Murray Brook Mine — Annual Ore Production[1]

Year	Ore Milled (t)	Ag (g/t)	Ag (g/t)
1989[2]	98 430	61.71	1.85
1990	388 003	49.37	2.06
1991	453 592	70.29	1.61
1992[3]	167 829	62.74	1.10
1993	0	–	–

Notes: Source is company annual reports.

[1] This was from the Gossan zone overlying the Murray Brook Zn–Pb–Cu–Ag–Au massive sulphide deposit. Total metal recovered during the life of the mine was 45,434 ounces (1.413 t) of gold and 346,457 ounces (10.77 t) of silver.

[2] Production began in September 1989.

[3] Gold ore was depleted in the summer of 1992.

SHOSHONITIC LAMPROPHYRE DYKES AT THE LAKE GEORGE ANTIMONY DEPOSIT, NEW BRUNSWICK: PETROCHEMICAL CHARACTERISTICS AND IMPLICATIONS FOR GOLD MINERALIZATION †

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Several east–west-trending, very steeply south-dipping narrow (< 4 m wide) Early Devonian lamprophyre dykes are found on the Lake George property and many more occur along the southern boundary of the Pokiok Batholith. These very fine-grained to medium-grained dykes are hornblende-phyric with abundant interstitial phlogopite, plagioclase (± K-feldspar), and minor apatite, titanite, and Fe–Ti oxides with later carbonate, quartz, and pyrite (± chalcopyrite). Argillic to sericitic alteration in these dykes is related to various episodes of Au–W–Mo and later Sb–Au mineralization in the area. Emplacement of the dykes seem to immediately precede the Lake George granodiorite, based on crosscutting relationships and earlier K–Ar dates. Three least-altered samples of lamprophyre dykes were identified from an existing dataset, based on their consistent composition and low abundances of mineralizing elements; they have background levels of Au (8 ± 8 ppm), Sb (9 ± 7 ppm), As (34 ± 26 ppm), Mo (< 2 ppm), and W (3 ± 1 ppm). Based on the geochemical data, these lamprophyre dykes are basaltic trachyandesitic in composition; they also have ultrapotassic geochemical characteristics with high MgO (> 10 wt.%), K_2O (> 5 wt.%), and K_2O/Na_2O (8.3 ± 4.2). Their bulk composition is consistent with fractionation with decreasing Mg# and compatible siderophile elements such as Cr and Ni, although these trends represent inter-dyke variations. Overall, they have immobile-element geochemical characteristics consistent with within-plate tholeiitic to alkalic mafic magmas that have arc geochemical associations (low Ti, Y, Nb, and high U, Th, La, Ce) similar to lamprophyric dykes of calc-alkaline affinity. Typically, these magmas are derived from low degrees of partial melting of phlogopite-bearing metasomatized mantle in a suprasubduction zone setting. The emplacement of these magmas as dykes reflect the existence of mantle-tapping structures with a local extensional geodynamic setting. This extensional environment may be key to the high level emplacement of the Lake George granodiorite that is responsible for the Au–W–Mo mineralizing event.

Plusieurs dykes de lamprophyre étroits (de moins de quatre mètres de largeur) du Dévonien précoce orientés d'est en ouest et s'inclinant très abruptement vers le sud, sont présents sur la concession du lac George, et de nombreux autres sont présents le long de la limite méridionale du batholithe de Pokiok. Ces dykes à grain très fin à moyen sont constitués de porphyre à hornblende avec une

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somme abondante de phlogopite interstitielle, du plagioclase (± feldspath potassique) et une quantité modeste d'apatite, de titanite et d'oxydes de Fe–Ti accompagnés de carbonate, de quartz et de pyrite (± chalcopyrite) plus tardifs. L'altération argileuse à sériciteuse dans ces dykes est apparentée à différents épisodes de minéralisation d'Au–W–Mo et une minéralisation ultérieure de Sb–Au dans le secteur. La mise en place des dykes semble avoir immédiatement précédé la granodiorite du lac George, selon les rapports transversaux et les dates antérieures d'apparition du K–Ar. Trois des échantillons de dykes de lamprophyre les moins altérés ont été identifiés au moyen d'un ensemble de données existant, d'après leur composition uniforme et leur abondance réduite d'éléments minéralisateurs; ils présentent des niveaux de base d'Au (8 ± 8 ppm), de Sb (9 ± 7 ppm), d'As (34 ± 26 ppm), de Mo (< 2 ppm) et de W (3 ± 1 ppm). Selon les données géochimiques, ces dykes de lamprophyre sont formés de trachyandésite et de basalte; ils possèdent également des caractéristiques géochimiques ultrapotassiques avec teneurs élevées en MgO (> 10 % pds), de K_2O (> 5 % pds) et de K_2O/Na_2O (8,3 ± 4,2). Leur composition apparente est révélatrice d'une cristallisation fractionnée avec réduction de la quantité de Mg et des éléments sidérophiles compatibles comme le Cr et le Ni, même si ces tendances représentent des variations entre les dykes. Ils possèdent dans l'ensemble des caractéristiques géochimiques d'éléments immobiles correspondant aux magmas intraplaques tholéiitiques à alcalins mafiques présentant des associations géochimiques d'arcs (faible teneur en Ti, Y et Nb et forte teneur en U, Th, La et Ce) semblables aux dykes lamprophyriques d'affinité calcoalcaline. Ces magmas proviennent habituellement des faibles degrés de fonte partielle d'un manteau métasomatisé phlogopitifère dans le milieu d'une zone de suprasubduction. L'intrusion de ces magmas sous forme de dykes témoigne de l'existence de structures de suffosion du manteau avec un milieu géodynamique d'extension locale. Cet environnement d'extension pourrait constituer un facteur clé de l'intrusion à un niveau élevé de la granodiorite du lac George, laquelle est à l'origine du phénomène de minéralisation d'Au–W–Mo.

INTRODUCTION

The Lake George antimony deposit (Figure 1), one of the largest Sb resources in North America (Scratch *et al.* 1984), has been opened intermittently since it was found in the late 1800s (Caron 1996) and closed most recently in 1997. Southern New Brunswick has recently attracted gold exploration related to intrusive systems that are traditionally known to host Sn–W–Mo mineralization (Ruitenberg and Fyffe 1982), but was also known to be associated with some gold mineralization (Seal II *et al.* 1987, 1988; Ruitenberg *et al.* 1990; Caron 1996; McLeod and McCutcheon 2000; Thorne and Lentz 2001). The Lake George area is now being examined from a multidisciplinary perspective to distill the important features suitable to enhance gold exploration (Chi *et al.* 2001). At the Lake George mine specifically, several generations of gold mineralization are known. The first episodes of gold mineralization (Stage I) are associated with replacement-style disseminated type to a W–Mo quartz–carbonate stockwork veining type that is spatially and temporally related to a cupola of Early Devonian granodioritic porphyry that discordantly intrudes the tightly folded, predominantly Early to Middle Silurian metasedimentary sequence (Seal II *et al.* 1987, 1988; Caron 1996; Yang *et al.* 2002a, b). Slightly younger gold mineralization is related to a polymetallic vein system (higher gold abundances) and to the latest antimony vein event (Stage II), which has low-grade gold (Scratch *et al.* 1984; Seal II *et al.* 1987, 1988).

Based on crosscutting relationships at Lake George (Seal II *et al.* 1987, 1988) and elsewhere in the region (Caron 1996), the east–west-trending lamprophyric to dioritic dykes (see Morrissy and Ruitenberg 1980) were inferred to intrude between the two pulses (Stage Ia,b) of the Au–W–Mo stockwork mineralizing

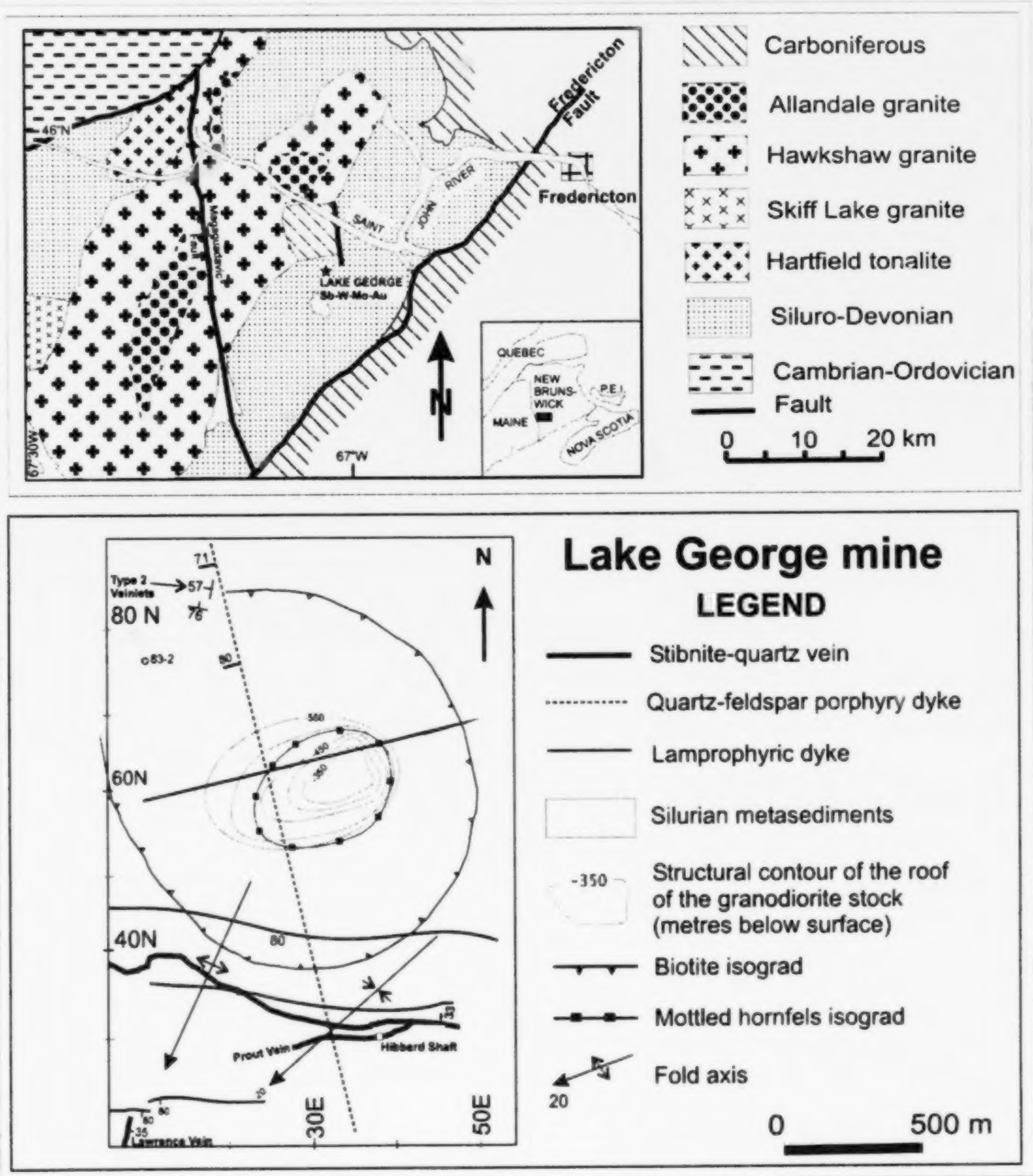

Figure 1. Location and general geology of the Lake George antimony mine, New Brunswick (modified after Seal *et al.* 1988).

event (see Seal II *et al.* 1988). These temporal relationships are supported by the K–Ar age dating (Seal 1984), although problems are evident with anomalously young ages, possibly because of the sericitic alteration superimposed onto these dykes during continued hydrothermal alteration in the region (Seal II *et al.* 1988; Caron 1996). However, the lamprophyre dykes seem to predate the granodioritic porphyry as they evidently do not crosscut it and host significant mineralization as a result of experiencing both Au–

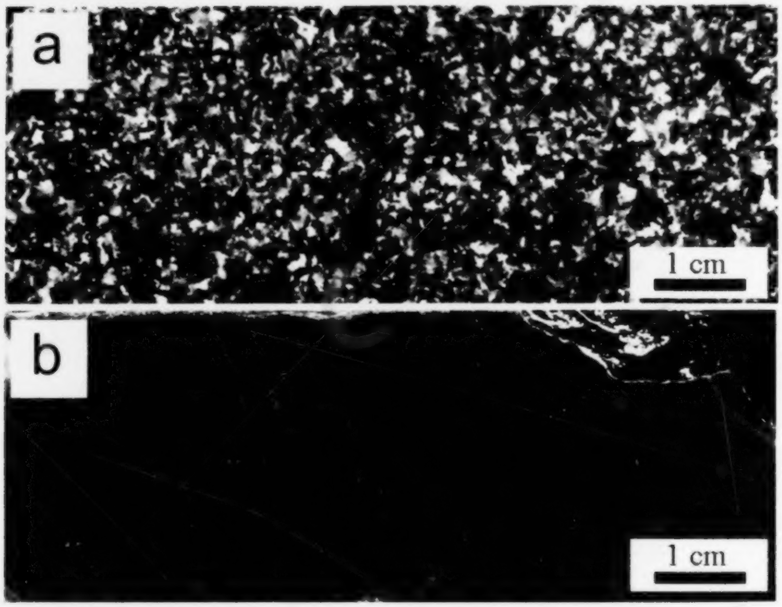

Figure 2. (a) Photograph of medium-grained lamprophyre from drill core (76-10A-96') at the Lake George deposit. (b) Photomicrograph of fine-grained lamprophyre from underground (DBJ-LG-78-2) at the Lake George deposit.

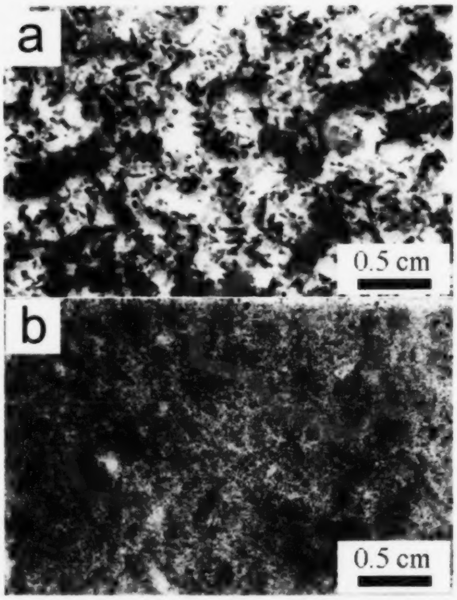

Figure 3. (a) Polished thin section photograph of medium-grained lamprophyre from drill core (76-10A-96') at the Lake George deposit. (b) Polished thin section photomicrograph of fine-grained lamprophyre from underground (DBJ-LG-78-2) at the Lake George deposit.

W–Mo (Stage I) and Au–Sb mineralizing events (Stage II) (Caron 1996). The close timing of these late kinematic lamprophyre dykes (earlier) to the calc-alkalic Pokiok Batholith and the Lake George granodioritic porphyry (later) is interesting. The fact that these shoshonitic mafic dykes have been noted to straddle the Stage I (a, b) Au–W–Mo mineralizing event at Lake George (Seal II *et al.* 1988) supports a more detailed analysis of their role in the formation of the gold mineralization in the Lake George area. A precise petrogenetic understanding and classification of this lamprophyric suite may shed insight into their significance from a regional tectonic perspective.

GEOCHRONOLOGIC CONSIDERATIONS

The Lower to Upper Silurian turbiditic sedimentary rocks of the Kingsclear Formation (Fredericton Zone, Fyffe and Fricker 1987) that host the various mineral deposits in the Lake George area were tightly folded (shallowly plunging northeast-trending structures) during the Acadian Orogeny (Morrissy and Ruitenberg 1980; Caron 1996). The Early Devonian Pokiok Batholith located about 3.5 km to the northwest, contact metamorphoses these folded metasedimentary rocks (O'Brien 1977; Caron 1996). This is consistent with the overprinting relationship of the hornfels aureole associated with the Lake George granodioritic porphyry (Seal II *et al.* 1988; Caron 1996). Therefore, these granodioritic to granitic intrusions are late tectonic with respect to the folding associated with the Acadian Orogeny in the region.

U–Pb age dating of the Hawkshaw granite (411 ± 1 Ma on titanite; Bevier and Whalen 1989, 1990; Whalen 1993) and the Lake George granodioritic porphyry (412 +5/-4 Ma U–Pb on zircon; M. McLeod, personal communication, 2001) and trace-element modelling (Yang *et al.* 2002a) support a genetic relationship. However, previous K–Ar age data from the Geological Survey of Canada on biotite from the porphyry indicated an age of 390 ± 7 Ma (Seal 1984). This is nearly coincident with the 382 ± 7 Ma age (actinolitic hornblende) from a lamprophyric dyke (Seal 1984). Both these younger ages probably reflect late closure to Ar diffusion possibly associated with hydrothermal alteration. Interestingly though, magmatic biotite from the lamprophyric dyke (415 ± 8 Ma) is older, but within the range of 411 and 413 (± 8) Ma from hydrothermal muscovite from late stage W–Mo (Au) mineralization (Type Ib) (Type II of Seal II *et al.* 1988) and the phyllic alteration mantling the Hibbard stibnite vein (Type II, 417 ± 8 Ma) (see Seal 1984; Seal II *et al.* 1988). This indicates that these undeformed lamprophyric dykes intrude the sequence immediately before or during the emplacement of the Lake George granodioritic satellite stock. The preservation of some of these older K–Ar ages indicates that rapid cooling (uplift?) occurred after the various mineralizing episodes, at least to temperatures where muscovite remained closed to Ar loss. These alkalic mafic dykes are variably altered throughout the region, although it is problematic to discern primary versus secondary hydrous calc-silicates and phlogopitic micas.

LAMPROPHYRIC DYKES

These narrow (0.3 to 4 m wide, but up to 20 m locally) east–west-trending lamprophyric dykes dip very steeply south (80°, Morrissy and Ruitenberg 1980; Seal II *et al.* 1988; Caron 1996) and seem to have an en echelon relationship to each other. In the Lake George structural subdomain, these dykes intrude orthogonally to the S_1 fabric (see poles to S_1; Caron 1996), but at a shallow angle to the surface trace of the Pokiok Batholith contact. They have a similar orthogonal trend to the late stibnite veins, although are much steeper than the veins. Within the mine area, there are more than 12 known dykes. With the exception of the quenched margins, these dykes (Figures 2a, b and 3a, b) are generally medium-grained (up to 0.4 cm) with a predominantly idiomorphic texture. This texture is marked by intercumulus plagioclase

Table 1. Whole-rock Geochemical Data from Lake George Lamprophyres

Sample	AR-110-90	AR-113-90	AR-154-90	Unaltered		Altered		Shaw Cove	
				$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
wt. %									
SiO_2	53.9	51.9	54.8	53.5	1.5	51.3	6.8	47.9	3.7
TiO_2	1.19	1.17	1.26	1.20	0.05	1.27	0.14	1.4	0.26
Al_2O_3	11.1	10.3	11.9	11.1	0.80	11.85	1.24	12.8	1.6
CaO	6.01	6.30	6.31	6.20	0.17	7.39	2.79	9.01	3.47
MgO	10.4	12.1	8.4	10.3	1.85	6.13	2.55	8.98	2.57
Na_2O	0.67	0.43	1.05	0.70	0.31	0.40	0.40	1.70	0.91
K_2O	5.15	5.52	4.65	5.10	0.44	3.62	1.24	4.81	1.42
$Fe_2O_3^T$	8.42	8.68	7.88	8.30	0.41	7.07	1.79	7.96	0.99
MnO	0.13	0.15	0.13	0.10	0.01	0.15	0.05		
P_2O	0.61	0.65	0.63	0.60	0.02	0.60	0.13	1.38	0.41
LOI	1.47	1.93	1.31	1.60	0.32	7.46	3.65	3.71	0.72
Total	99.1	99.1	98.3						
Mg#	51.6	54.6	47.9	51.6		42.8		49.2	
ppm									
Au (ppb)	5	17	2	8	8	406	1003	–	–
B	23	10	11	15	7	74	80	–	–
Sc	20.4	20.8	21.7	21.0	0.7	20.3	2.6	24.3	2.0
V	219	199	251	223	26	217	30	–	–
Co	42	47	35	41	6	38	6	44	7
Ni	329	410	243	327	84	307	75	–	–
Cu	55	33	81	56	24	59	16	–	–
Zn	121	132	104	119	14	120	61	–	–
As	10	62	31	34	26	4374	11075	–	–
Mo	<2	<2	<2	–	–	6	9	–	–
Sb	4.1	4.4	17.0	8.5	7.4	442	577	–	–
Cs	18.5	26.0	17.7	20.7	4.6	14.6	6.3	0.67	0.33
La	49.5	43.1	54.0	48.9	5.5	55.6	19.0	184	25
Ce	105	91	110	102.0	10	108	31	375	45
Nd	51	45	54	50	5	49	12	160	14
Sm	10.2	9.5	11.1	10.3	0.8	9.9	2.2	25.6	2.1
Eu	2.09	2.16	2.58	2.30	0.27	2.45	0.46	6.43	0.50
Tb	1.2	0.9	0.9	1.0	0.2	1.1	0.3	1.6	0.2
Yb	2.41	1.93	2.61	2.30	0.35	2.51	0.44	2.08	0.43
Lu	0.34	0.28	0.38	0.30	0.05	0.34	0.07	0.22	0.04
Hf	9.4	8.1	9.9	9.1	0.9	9.2	1.0	13.4	1.2
W	3	3	4	3	1	38	37	–	–
Pb	13	14	38	22	14	24	39	–	–
Bi	0.8	3.3	0.8	1.6	1.4	2.6	2.6	–	–
Th	22	19	24	22	3	22	3	33	3
U	6.1	5.3	6.6	6.0	0.7	6.3	0.9	5.6	0.5
Cr	682	859	519	687	170	621	118	455	110
Rb	241	275	217	244	29	168	56	57	11
Sr	385	349	561	432	113	334	136	1030	380
Y	33	28	25	29	4	31	8	20	1
Zr	304	267	318	296	26	333	44	437	97
Nb	11	25	26	20	8	24	8	–	–
Ba	1520	1470	1770	1587	161	642	558	3056	972
Zr/TiO_2	0.026	0.023	0.025	0.025	0.001	0.026	0.003	–	–
Nb/Y	0.33	0.89	1.04	0.80	0.37	0.82	0.38	–	–
Zr/Hf	32.3	33.0	32.1	32.5	0.4	36.3	2.8	–	–
K_2O/Na_2O	7.7	12.8	4.4	8.3	4.2	17.5	10.8	–	–
La_n/Lu_n	15.1	16.0	14.8	15.3	0.6	17.3	4.8	–	–
Th/U	3.6	3.6	3.6	3.6	0.0	3.5	0.4	–	–
Ti/V	32.6	35.3	30.1	32.7	2.6	35.3	3.7	–	–

NOTES: "Unaltered" represents an average of the three least-altered samples (Caron 1996). "Altered" represents an average of 27 altered lamprophyres (Caron 1996). "Shaw Cove" is Devonian Shaw Cove lamprophyre (n = 22) average (Simpson 1980). Total iron is expressed as $Fe_2O_3^T$. Mg# = Mg/(Mg + Fe); $\bar{x}$ = mean; SD = standard deviation; – indicates unanalyzed.

(± orthoclase)–phlogopitic mica network that is slightly finer grained than the associated phenocrysts of brown to green zoned amphibole (see also Seal II *et al.* 1988; Caron 1996) that may have replaced clinopyroxene. The proportion of mica locally seems more abundant than the coarser phenocrysts of hornblende. Carbonate is also present in apparent equilibrium with the phenocryst assemblage, although later carbonate veins are evident. Fine-grained graphic and myrmekitic texture is evident locally. These dykes also locally have interstitial quartz with carbonate and pyrite (± chalcopyrite); therefore, they are inferred to be hydrothermal and may be linked to myrmekite formation. Their weakly porphyritic nature, general mineralogy, and dyke-like nature is consistent with the term lamprophyre as previously noted (Seal II *et al.* 1988), although further mineralogical work is needed to ascertain if these are indeed spessartite lamprophyres (see Seal II *et al.* 1988). The narrower lamprophyre dykes (<1 m) tend to be finer grained than the wider dykes. They are generally interpreted as planar intrusions in horizontal and vertical dimensions consistent with their sharp boundaries in the mine and drill core, although the 4 m wide dyke on the 850 m level pinches into the gold breccia zone and is apparently offset, with a curvilinear attribute.

GEOCHEMISTRY OF DYKES

Geochemical data on these lamprophyres is extensive, although many are evidently hydrothermally altered (argillic to sericitic), based on high Mo, W, Au, Sb, and (or) As contents (Caron 1996). Based on this, three least-altered samples were selected (Table 1), which have background levels of Au (8 ± 8 ppb), Sb (9 ± 7 ppm), As (34 ± 26 ppm), Mo (< 2 ppm), and W (3 ± 1 ppm). A perusal of the geochemical data, in particular elements that are most typically immobile (see Jenner 1996) shows that these dykes are chemically related (Table 1).

For the three least-altered samples, the average SiO_2 (53.5 ± 1.5 wt.%) and total alkalis ($Na_2O+K_2O = 5.8 \pm 0.8$ wt.%) are consistent with a basaltic trachyandesite composition (LeMaitre 1989). SiO_2, $Fe_2O_3^T$, CaO, Na_2O+K_2O, TiO_2, and P_2O_5 variations of the least-altered samples relative to MgO (Figure 4) are all consistent with fractionating alkalic mafic magmas. The much greater variation in the major elements in the altered lamprophyres (Figure 4) reflects the geochemical effects of argillic to sericitic alteration superimposed on these dykes by the various hydrothermal episodes at Lake George (see Caron (1996) for a detailed discussion). The covariation in $Fe_2O_3^T$ and MgO (Figure 4b) and relatively low TiO_2 (Figure 4e) in the freshest lamprophyres are consistent with suprasubduction zone magmas of calc-alkaline association. The systematic decrease in Cr and Ni with decreasing MgO content (Figure 5) is consistent with these magmas tapping a fractionating mafic source at depth. It is suspected that each of the dykes represents an episode of eruption during fractionation, although more detailed work is needed to ascertain this. The lower CaO and total alkalis (Figure 4c, d) resemble shoshonitic mafic suites typically noted in mature arc settings. The high MgO (> 10 wt.%), Mg# (52–55), K_2O (> 5 wt.%), BaO (0.18 wt.%), and K_2O/Na_2O (4.2) are typical of ultrapotassic intrusions (see Rock 1987; Shaw 1996). These geochemical characteristics together with the mineralogy are typical of shoshonitic lamprophyres (see Seal II *et al.* 1988) of calc-alkaline affinity.

The Zr/P_2O_5 and TiO_2 contents of the dyke are relatively low, although still within the alkaline field (Figure 6a) using the Winchester and Floyd (1975) basalt discrimination diagram. The low Nb/Y (0.76), Ti/Y (200–300), and Zr/TiO_2 (0.025) contents (Figure 6b, see Winchester and Floyd 1977; Pearce 1982) are also like basaltic trachyandesitic rocks with transitional characteristics to alkali and tholeiitic basalts. These moderate Nb/Y contents together are consistent with continental rift basalts, but the TiO_2 contents are relatively low resembling tholeiitic to calc-alkaline basaltic rocks, but is consistent with shoshonitic

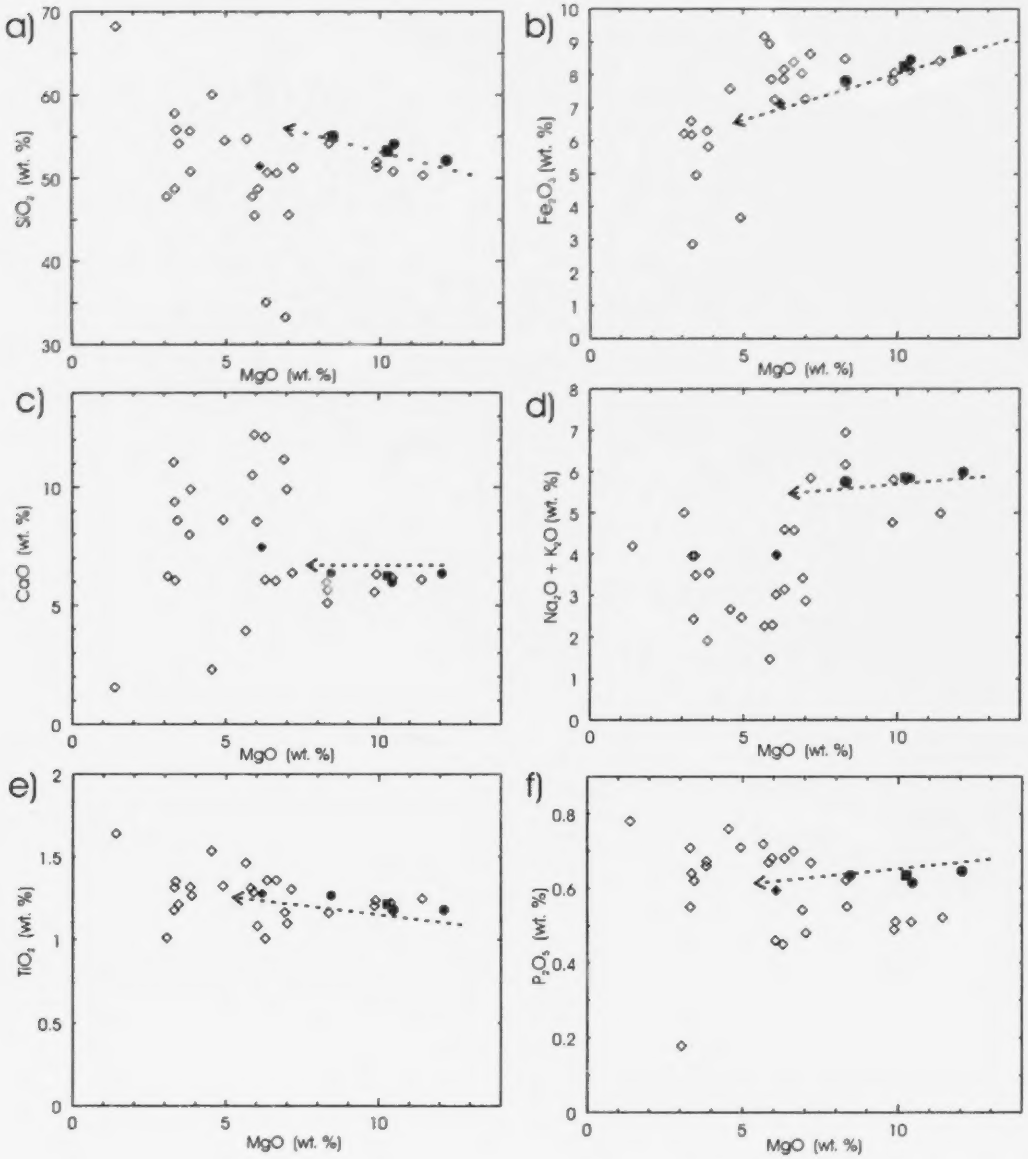

Figure 4. MgO versus (a) SiO_2, (b) $Fe_2O_3^T$, (c) CaO, (d) Na_2O+K_2O, (e) TiO_2, and (f) P_2O_5, illustrating the three least-altered (•), average least-altered (▪), altered (◇), and average altered (♦) lamprophyres from Lake George. The dotted arrow represents a hypothetical fractionation array based on the three least-altered samples.

lamprophyres (see Rock 1987). This causes the sample data to plot inconsistently on Ti-based geochemical discrimination diagrams, relative to other trace-element systematics. Pearce (1983) noted this range of Nb/Y (0.3 to 1.0) to be typical of tholeiitic to transitional within-plate basaltic rocks. The relatively high Zr (296 ppm), Zr/Y (10.3), and Zr–Nb–Y systematics are also consistent with within-plate alkalic mafic magmas (Figure 7a, Meschede 1986), although they most closely resemble Roman Province ultrapotassic rocks (Rock 1987) of calc-alkaline affinity. The moderate Ti/V (33 ± 3) resemble either continental-flood

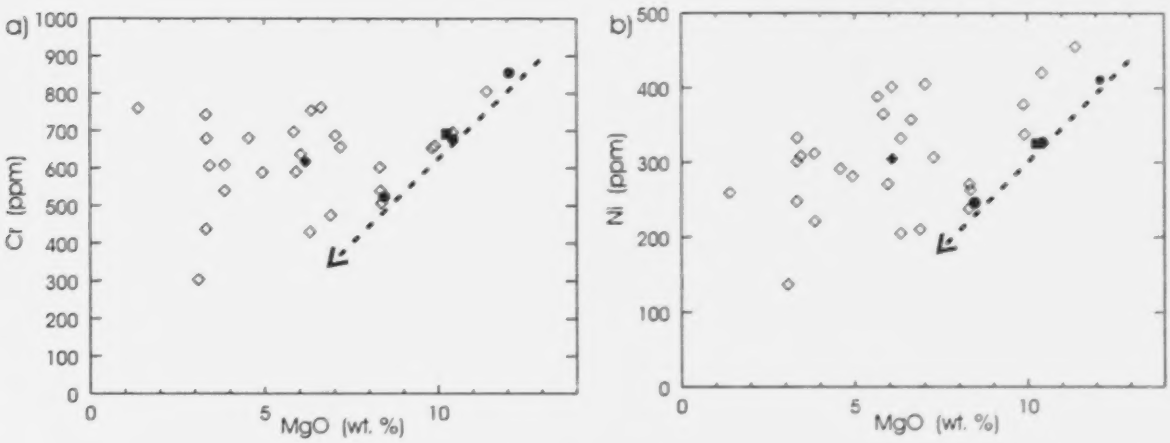

Figure 5. MgO versus (a) Cr and (b) Ni, illustrating the three least-altered (•), average least-altered (▪), altered (◇), and average altered (♦) lamprophyres from Lake George. The dotted arrow represents a hypothetical fractionation array based on the three least-altered samples.

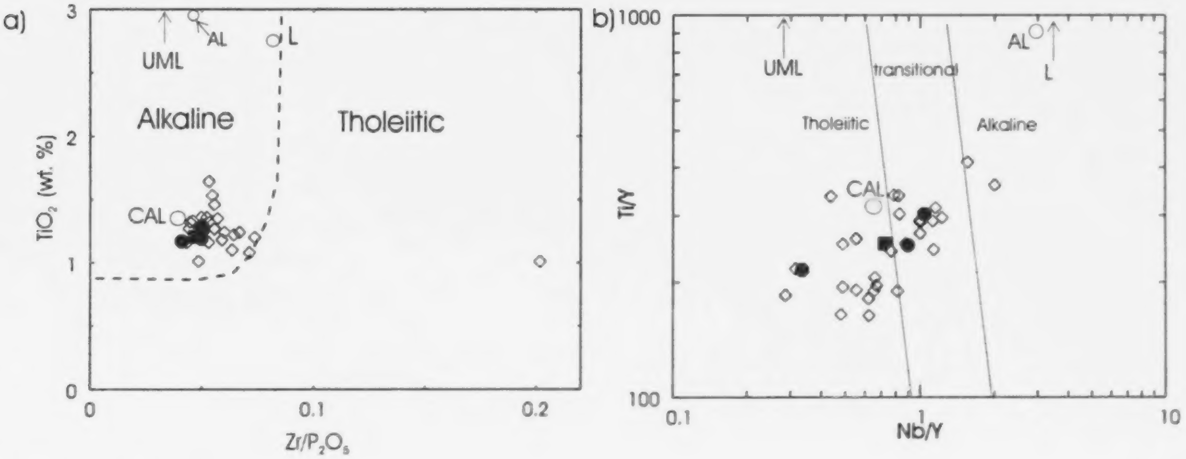

Figure 6. (a) TiO$_2$ versus Zr/P$_2$O$_5$ mafic geochemical discrimination diagram (Winchester and Floyd 1975) and (b) Ti/Y versus Nb/Y mafic geochemical discrimination diagram (Pearce 1982) illustrating the composition of three least-altered (•), average least-altered (▪), altered (◇), and average altered (♦) lamprophyres from Lake George. Also illustrated are the typical range of values for ultramafic lamprophyres (**UML**), alkaline lamprophyres (**AL**), calc-alkaline lamprophyres (**CAL**), and lamproites (**L**) from the compilation of Rock (1987).

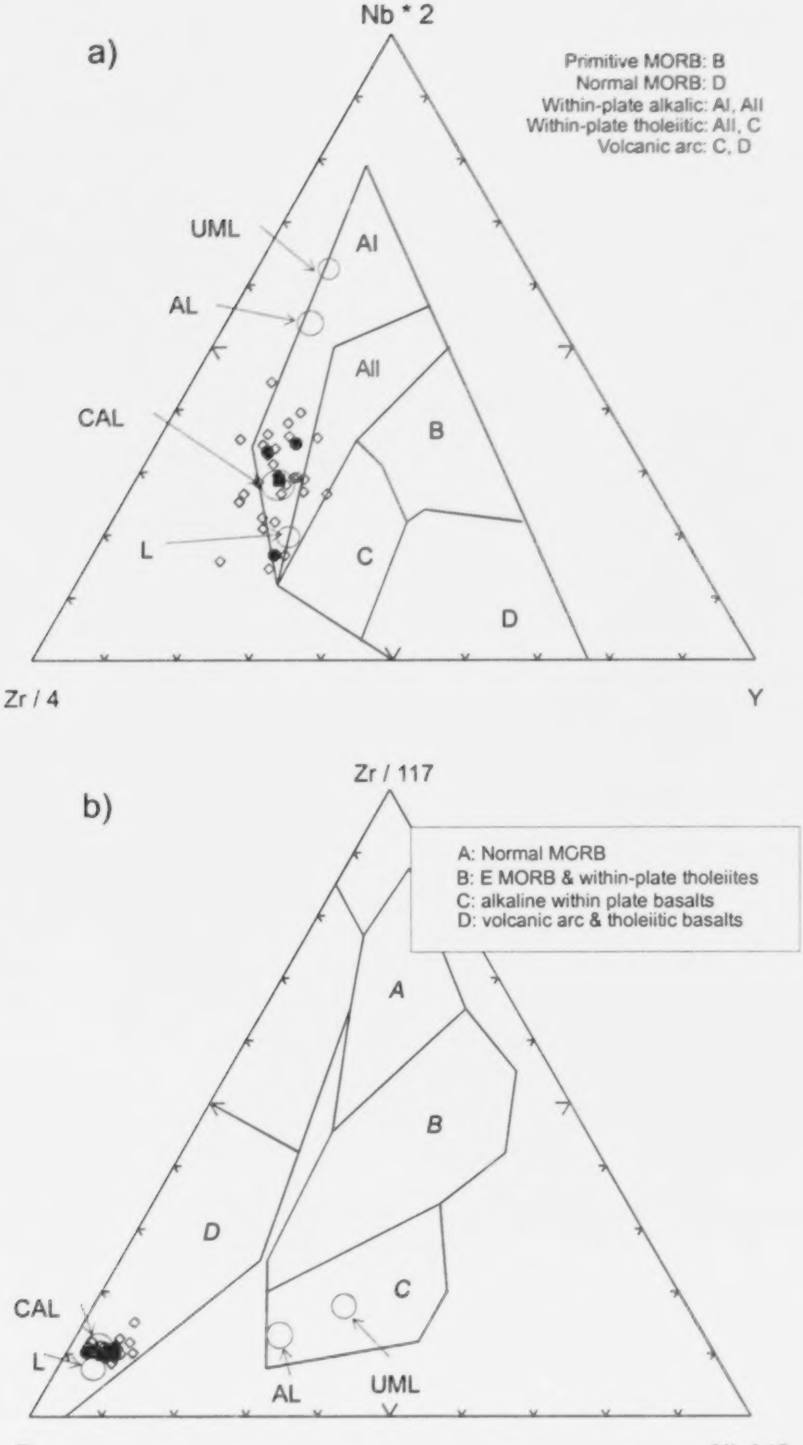

Figure 7. (a) Zr–Nb–Y ternary mafic geochemical discrimination diagram (Meschede 1986) and (b) Th–Zr–Nb ternary geochemical discrimination diagram (Wood 1980) illustrating the three least-altered (•), average least-altered (▪), altered (◇), and average altered (♦) lamprophyres from Lake George. Also illustrated are the typical range of values for ultramafic lamprophyres (**UML**), alkaline lamprophyres (**AL**), calc-alkaline lamprophyres (**CAL**), and lamproites (**L**) from the compilation of Rock (1987).

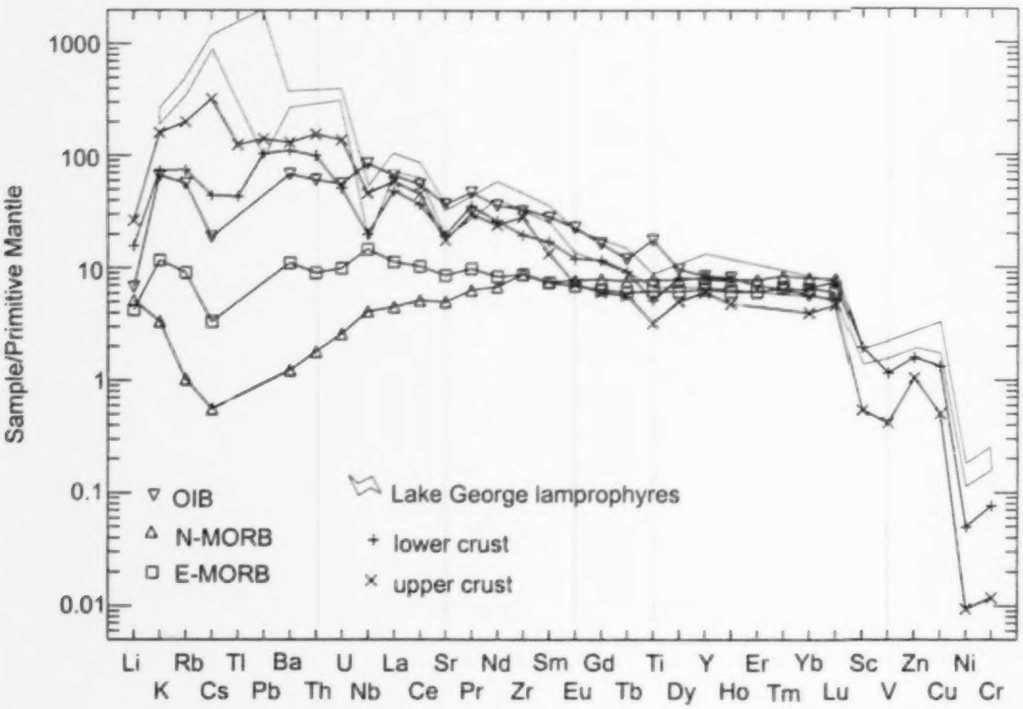

Figure 8. Primitive-mantle-normalized, extended trace-element spider diagram illustrating the three least-altered Lake George lamprophyres relative to N-MORB (normal-type mid-ocean-ridge basalt), E-MORB (enriched-type mid-ocean-ridge basalt), OIB (ocean-island basalt), and primitive mantle (Sun and McDonough 1989), as well as upper and lower crustal averages (Wedepohl 1995).

or back-arc-basin basaltic rocks, but plot close to the calc-alkaline arc field (Shervais 1982) as well, suggesting suprasubduction mantle wedge processes may be involved. Very high Th contents (22 ppm) relative to Zr and Nb in the dykes suggest volcanic-arc (Figures 7b and 8; Wood 1980) rather than within-plate alkaline affinities; this is analogous to shoshonitic lamproite to lamprophyres of calc-alkaline affinity. Therefore, the relatively low TiO_2 and Nb contents (Figure 8) may reflect preferential retention in the slab or mantle wedge, relative to other metasomatized incompatible constituents.

DISCUSSION

Relative to the subdivisions of Foley *et al.* (1987), the Lake George lamprophyres typically fall on the margin between Group III (Roman Province type) and Group I (lamproites), although the low TiO_2, and lower K_2O and incompatible elements are most like those of calc-alkaline association analogous to the Roman Province. These shoshonitic mafic dykes probably represent very low degrees of partial melting, with minimal crustal contamination. Typically, these melts represent much less that 5% partial melting of K-rich phlogopite-bearing metasomatized mantle, generated by subduction slab devolatilization and fluxing of subducted pelagic sediments that reacted with the depleted mantle wedge (see Faure 2001), analogous to the interpretation for ultrapotassic Roman Province suites (Shaw 1996). Typically, shoshonitic lamprophyres are emplaced within extensional features in mature-arc to syncollisional environments reflecting transient extensional (transpressional?) episodes within the overall evolving orogen. Interestingly, the close association of lamprophyres to shear-zone-hosted gold deposits (Kerrich and Wyman 1994) is usually attributed to the fact that they commonly occur in major mantle tapping structures and that mafic magma advective heat transfer enhances further devolatilization. Analogously, mafic magmas of various types commonly intrude zones of transtension and may be associated with heat transfer at the base of the crust (see Thorne and Lentz, in press). Therefore, the association of ultrapotassic mafic magmas may only reflect the source region that the transpressional environment is tapping at depth.

RECOMMENDATIONS

Rock (1987) has a few other pertinent observations on the relationship of lamprophyres to mineralized porphyry systems that requires more information to test their applicability to the Lake George mineralized system. Detailed mineral-chemical and whole-rock geochemical data are needed on a suite of least-altered samples of these lamprophyres. Also, lamprophyre crosscutting relationships need to be re-examined, especially the timing of the early phase of mineralization, the felsic dyke, and the granodioritic porphyry. Lastly, Ar–Ar dating of the least-altered igneous hornblende and biotite-phlogopite is required to determine the age of these dykes relative to the surrounding intrusions and mineralization.

ACKNOWLEDGMENTS

APOCAN, in particular Wayne Marshall, allowed us access to the information and drill core on the mine site. The Natural Sciences and Engineering Research Council of Canada provided funding for this project. Discussions with L. Fyffe and M. McLeod helped with our understanding of the local geology and structure. Editing of this manuscript by Les Fyffe is gratefully acknowledged.

REFERENCES

BEVIER, M.L. and WHALEN, J.B. 1989. U–Pb geochronology of Silurian granites, Miramichi Terrane, New Brunswick. *In* Radiogenic Age and Isotope Studies: Report 3. Geological Survey of Canada, Paper 89-2, pp. 93–100.

BEVIER, M.L. and WHALEN, J.B. 1990. Tectonic significance of Silurian magmatism in the Canadian Appalachians. Geology, 18: 411-414.

CARON, A. 1996. Geology of the Pokiok Batholith aureole, with emphasis on the Lake George Mine, York County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Geoscience Report 94-2, 91 p.

CHI, G., WATTERS, S., FYFFE, L.R., MCLEOD, M.J., LENTZ, D.R., YANG, X., THORNE, K., CASTONGUAY, S., DAVIS, W., TREMBLAY, A., DUBÉ, B., SAVARD, M.M., JOHNSON, S., LAUZIÈRE, K., RENNICK, P., and HOY, D. 2001. Metallogeny of intrusion-related gold systems in southwestern New Brunswick. *In* Abstracts, 2001: 26th Annual Review of Activities. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 2001-1, pp. 15–16.

FAURE, G. 2001. Origin of Igneous Rocks: The Isotopic Evidence. Springer, New York, 496 p.

FOLEY, S.F., VENTURELLI, G., GREEN, D.H., and TOSCANI, L. 1987. The ultrapotassic rocks: characteristics, classifications and constraints for petrogenetic models. Earth Science Reviews, **24**: 81–134.

FYFFE, L.R. and FRICKER, A. 1987. Tectonostratigraphic terrane analysis of New Brunswick. Maritime Sediments and Atlantic Geology, **23**: 113–122.

JENNER, G.A. 1996. Trace element geochemistry of igneous rocks: geochemical nomenclature and analytical geochemistry. *In* Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration. *Edited by* D.A. Wyman. Geological Association of Canada, Short Course Notes, **12**: 51–77.

KERRICH, R. and WYMAN, D.A. 1994. The mesothermal gold–lamprophyre association: significance for an accretionary geodynamic setting, supercontinental cycles, and metallogenic processes. Mineralogy and Petrology, **51**: 147–172.

LE MAITRE, R.W. (ed.) 1989. A Classification of Igneous Rocks and Glossary of Terms. Blackwell, Oxford, 193 p.

MCLEOD, M.J. and MCCUTCHEON, S.R. 2000. Gold environments in New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-28.

MESCHEDE, M. 1986. A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb–Zr–Y diagram. Chemical Geology, **56**: 207–218.

MORRISSY, C.J. and RUITENBERG, A.A. 1980. Geology of the Lake George antimony deposit southern New Brunswick. Canadian Institute of Mining and Metallurgy Bulletin, **73**: 79–84.

O'BRIEN, B.H. 1977. Pre-Acadian deformation, metamorphism, and intrusion in the vicinity of the Pokiok Pluton, west-central New Brunswick, and its regional implications. Canadian Journal of Earth Sciences, **14**: 1796–1808.

PEARCE, J.A. 1982. Trace element characteristics of lavas from destructive plate boundaries. *In* Andesites: Orogenic Andesites and Related Rocks. *Edited by* R.S. Thorpe. Wiley, New York, pp. 525–548.

PEARCE, J.A. 1983. Role of the sub-continental lithosphere in magma genesis at active continental margins. *In* Continental Basalts and Mantle Xenoliths. *Edited by* C.J. Hawkesworth and M.J. Norry. Shiva Publishing Limited, pp. 230–249.

ROCK, N.M.S. 1987. The nature and origin of lamprophyres: an overview. *In* Alkaline Igneous Rocks. *Edited by* J.G. Fitton and B.G.J. Upton. Geological Society Special Publication No. 30, pp. 191–226.

RUITENBERG, A.A. and FYFFE, L.R. 1982. Mineral deposits associated with granitoid intrusions and related subvolcanic stocks in New Brunswick and their relationship to Appalachian tectonic evolution. Canadian Institute of Mining and Metallurgy, **75**: 83–97.

RUITENBERG, A.A., JOHNSON, S.C., and FYFFE, L.R. 1990. Epigenetic Gold Deposits and their Tectonic Setting in the New Brunswick Appalachians. The Canadian Institute of Mining and Metallurgy, 83, no. 934: 43-55.

SCRATCH, R.B., WATSON, G.P., KERRICH, R., and HUTCHINSON, R.W. 1984. Fracture-controlled antimony–quartz mineralization, Lake George deposit, New Brunswick: mineralogy, geochemistry, alteration, and hydrothermal regimes. Economic Geology, **79**: 1159–1186.

SEAL, R.R. 1984. The Lake George W–Mo stockwork deposit, south-western New Brunswick. Unpublished M.Sc. thesis, Queen's University, Kingston, Ontario, 202 p.

SEAL II, R.R., CLARK, A.H., and MORRISSY, C.J. 1987. Stockwork tungsten (scheelite)–molybdenum mineralization, Lake George, southwestern New Brunswick. Economic Geology, **82**: 1259–1282.

SEAL II, R.R., CLARK, A.H., and MORRISSY, C.J. 1988. Lake George, southwestern New Brunswick: a Silurian, multi-stage, polymetallic (Sb–W–Mo–Au–base-metal) hydrothermal centre. *In* Recent Advances in the Geology of Granite-Related Mineral Deposits. *Edited by* R.P. Taylor and D.F. Strong. Canadian Institute of Mining and Metallurgy, Special Volume 39, pp. 252–264.

SHAW, C.S.J. 1996. The petrology and petrogenesis of Roman Province-type lavas and ultrapotassic leucitites. *In* Undersaturated Alkaline Rocks: Mineralogy, Petrogenesis, and Economic Potential. *Edited by* R.H. Mitchell. Mineralogical Association of Canada, Short Course 24, pp. 175–192.

SHERVAIS, J.W. 1982. Ti–V plots and the petrogenesis of modern and ophiolitic lavas. Earth and Planetary Science Letters, **59**: 101–118.

SIMPSON, E.L. 1980. Mineralogy and geochemistry of an ocellar minette sill, northern New Brunswick. Unpublished M.Sc. thesis, University of New Brunswick, Fredericton, New Brunswick, 208 p.

SUN, S.-S. and MCDONOUGH, W.F. 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. *In* Magmatism in Ocean Basins. *Edited by* A.D. Saunders and M.J. Norry, Geological Society Special Publication 42, pp. 313–345.

THORNE, K.G. and LENTZ, D.R. 2001. Potential for gold deposits associated with evolved Sn–W–Mo granitic magmatism in southwestern and central New Brunswick. ORE Group Newsletter, **2**: 1, 4–7.

THORNE, K.G. and LENTZ, D.R. In press. Geochemistry and petrogenesis of the East Branch Brook metagabbroic dykes in the Sawyer Brook Fault zone, Clarence Stream gold prospect, southwestern New Brunswick. Atlantic Geology.

WEDEPOHL, K.H. 1995. The composition of the continental crust. Geochimica et Cosmochimica Acta, **59**: 1217–1232.

WHALEN, J.B. 1993. Geology, petrography, and geochemistry of Appalachian granites in New Brunswick and Gaspésie, Quebec. Geological Survey of Canada, Bulletin 436, 124 p.

WINCHESTER, J.A. and FLOYD, P.A. 1975. Identification and discrimination of altered and metamorphosed volcanic rocks using immobile elements. Chemical Geology, **21**: 291–306.

WINCHESTER, J.A. and FLOYD, P.A. 1977. Geochemical discrimination of different magma series and their differentiation products using immobile elements. Chemical Geology, **23**: 325–343.

WOOD, D.A. 1980. The application of a Th–Hf–Ta diagram to problems of tectonomagmatic classification and to establishing the nature of crustal contamination of basaltic lavas of the British Tertiary volcanic province. Earth and Planetary Science Letters, **50**: 11–30.

YANG, X., LENTZ, D.R., and CHI, G. 2002a. Petrochemistry of Lake George granodioritic stock and related gold mineralization, York County, New Brunswick. Geological Survey of Canada, Current Research 2002-D7, pp. 1–10.

YANG, X., LENTZ, D.R., HALL, D.C., and CHI, G. 2002b. The petrology of the Lake George Granodiorite stock, New Brunswick: implications for crystallization conditions, volatile exsolution, and W–Mo–Au–Sb mineralization. Geological Survey of Canada, Current Research 2002-E14, pp. 1–12.

PRELIMINARY ANALYSIS OF THE CONTROLS ON THE VARIOUS EPISODES OF GOLD MINERALIZATION AT THE LAKE GEORGE ANTIMONY DEPOSIT, NEW BRUNSWICK †

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LENTZ, D.R., THORNE, K. and YANG, X. 2002. Preliminary analysis of the controls on the various episodes of gold mineralization at the Lake George antimony deposit, New Brunswick. *In* Current Research 2001. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Mineral Resource Report 2002-4, pp. 55–79.

Previous geochemical studies around the Lake George deposit have identified an extensive zone of gold mineralization associated with the W–Mo disseminated replacement and vein styles of stockwork mineralization within the contact aureole of the Lake George porphyritic granodiorite, as well as gold within the stibnite–quartz mineralized veins. Using existing descriptions, petrography, and geochemical data from the sedimentary rocks and the intrusion, there is a strong association of gold with quartz–carbonate stockwork vein and breccia development that have produced pronounced zones of grey alteration (very fine-grained arsenopyrite–pyrite–carbonate–sericite–rutile) to orange–yellow buff alteration (minor sulphides–sericite). Geochemically, As, W, and Mo correlate with gold (r = 0.85, 0.88, and 0.34, respectively) enrichment, but there is generally no association with Sb within the W–Mo zone. There are low amounts of gold in the stibnite–quartz veins (110 ppb). This supports a genesis for gold most closely related to the early W–Mo mineralizing events that are associated with arsenopyrite and arsenian pyrite. Gold is also significantly associated with low SiO_2 (r = -0.92) and Na_2O (r = -0.36), and high $Fe_2O_3^T$ (r = 0.55), K_2O (r = 0.64), and CaO (r = 0.90), which is consistent with the petrographic descriptions of the grey and orange–yellow buff alteration zones mantling the narrow sulphide–quartz–carbonate veins. The significant correlation between Au and $Fe_2O_3^T$ may be attributed to gold deposition through sulphur fixation reactions during fluid interaction with iron-enriched lithologies (i.e., lamprophyre dykes).

Since previous researchers attributed the earlier W–Mo and later Sb mineralizing events to local magmatic–hydrothermal processes associated with the emplacement and crystallization of the Lake George granodioritic porphyry, it is reasonable to suggest that these same processes are responsible for the gold-related mineralizing systems as well.

Des études géochimiques précédemment réalisées près du gîte du lac George ont défini une zone étendue de minéralisation aurifère associée au remplacement disséminé du W–Mo et aux types de filons d'une minéralisation de stockwerk à l'intérieur de l'auréole de contact de la granodiorite porphyrique du lac George, et ont relevé de l'or à l'intérieur de filons minéralisés de stibnite-quartz. L'utilisation des descriptions existantes, de la pétrographie et des données géochimiques

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des roches sédimentaires ainsi que de l'intrusion, révèlent une association étroite de l'or avec l'apparition des brèches et des filons de stockwerk de quartz–carbonate qui ont produit des zones prononcées d'altération grises (arsénopyrite–pyrite–carbonate–séricite–rutile à grain très fin) à chamois jaune orangé (sulphides–séricite en quantité limitée). D'un point de vue géochimique, l'As, le W et le Mo sont corrélés à l'enrichissement en or (r = 0,85, 0,88, et 0,34, respectivement), mais on ne relève généralement aucune association avec le Sb à l'intérieur de la zone de W–Mo. De faibles quantités d'or sont présentes dans les filons de stibnite–quartz (110 parties par milliard). Cette constatation appuie l'hypothèse que l'origine de l'or serait plus étroitement apparentée à des phénomènes de minéralisation précoce du W–Mo associés à l'arsénopyrite et à la pyrite arsénicale. L'or est aussi associé dans une grande mesure à des concentrations faibles de SiO_2 (r = -0,92) et de Na_2O (r = 0,36) ainsi qu'à des concentrations élevées de $Fe_2O_3^T$ (r = 0,55), de K_2O (r = 0,64) et de CaO (r = 0,90), ce qui correspond aux descriptions pétrographiques des zones d'altération grises et chamois jaune orangé recouvrant les filons étroits de sulfure–quartz–carbonate. La corrélation déterminante entre l'Au et le $Fe_2O_3^T$ peut être attribuée au dépôt de l'or en vertu de réactions de fixation du soufre au cours de l'interaction des fluides avec les lithologies enrichies en fer. (p. ex. dykes de lamprophyre).

Étant donné que les chercheurs antérieurs ont attribué les phénomènes de minéralisation précoce du W–Mo et de minéralisation tardive du Sb aux processus magmatiques–hydrothermaux locaux associés à l'intrusion et à la cristallisation du porphyre granodioritique du lac George, il est raisonnable d'avancer que ces mêmes processus ont également engendré les systèmes minéralisateurs aurifères.

INTRODUCTION

The recent recognition of significant gold-related intrusive systems associated with Sn–W–Mo granitoid intrusions worldwide (Thompson *et al.* 1999; Lang *et al.* 2000; Thompson and Newberry 2000; Lang and Baker 2001) and new discoveries of high-grade gold in southern New Brunswick with this association, has resulted in a re-analysis of similar systems in the New Brunswick portion of the Appalachians (McLeod and McCutcheon 2000; Thorne and Lentz 2001). Earlier literature referring to mineralization associated with various intrusive systems (the Lake George mine, e.g., Ruitenberg *et al.* 1990), together with these preliminary re-assessments and the literature review, were encouraging for the local existence of intrusion-related gold deposits. Exploration successes by Freewest Resources Canada Incorporated at the new Poplar Mountain and Clarence Stream discoveries has helped spawn further exploration and research on these particular types of gold deposits in the region.

To investigate these types of systems, a federal–provincial Targeted Geoscience Initiative (TGI) project has been initiated to examine gold-mineralizing intrusive systems in southwestern New Brunswick (Chi *et al.* 2001). As part of this TGI project, the Lake George Au–W–Mo and Au–Sb deposits are being studied in more detail by the authors. The general form and distribution of gold in and around the Lake George antimony vein deposit and associated polymetallic veins, and W–Mo stockwork mineralization has only been briefly described in several papers (Scratch *et al.* 1984; Seal II *et al.* 1987, 1988; Davison 1988; Harris 1990; Morrissy 1991a, b; Caron 1996). However, the detailed controls on the gold mineralization in these settings have received little attention.

This preliminary communication reviews and builds on existing descriptions and geochemistry of these various stages of gold mineralization by Angela Roy, Sheila Watters, and Alain Caron (Caron 1996), with emphasis on the gold-enriched systems. This general information is used so as to develop future research priorities toward ascertaining the controls on gold mineralization in the region. As part of this overall project, 190 crushed samples from the earlier gold study on drill core from the Lake George property (Morrissy 1991a) have been re-analysed by instrumental neutron activation analysis (INAA; see Lentz, in press). The very preliminary results of that study will augment this analysis.

GEOLOGICAL SETTING

The various mineral deposits at Lake George (Figure 1) include W–Mo mineralization (Type I), polymetallic veins (Type II), and Hibbard, Lawrence, and Prout antimony veins (Type III). Lower Silurian, locally calcareous or marly turbiditic sediments (Seal II *et al.* 1987, 1988; Caron 1996) of the Kingsclear Group (Fredericton Trough; Fyffe and Fricker 1987) comprise the host rocks to these deposits. These rocks are regionally metamorphosed to greenschist grade and tightly folded into upright to steeply northwest-dipping, northeast-trending, doubly plunging anticlines and synclines with axial planar cleavage (Caron 1996). The overall trend of units in the Kingsclear Group parallels the southern margin of the syn- to late-tectonic Early Devonian granitic to granodioritic Pokiok Batholith (Whalen 1993). Narrow shoshonitic lamprophyre dykes of calc-alkaline affinity intrude in an overall east–west orientation and generally dip steeply southward (Lentz *et al.* 2002), which in turn are intruded by a 3–5 m wide, north-northwest-trending quartz–feldspar porphyry dyke (see Procyshyn and Morrissy 1990). Intruding the entire package of metasediments and dykes is the Lake George quartz–hornblende–plagioclase porphyritic granodiorite (Yang *et al.* 2002a, b) that has reduced I-type characteristics similar to other intermediate intrusions associated with gold deposits (Yang *et al.* 2002a). A sample of this medium-grained, seriate granodiorite collected from the underground workings yielded a U–Pb zircon age of 414 ± 2 Ma (M.J. McLeod, personal communication, 2002). This age is coeval (within error) with the Hawkshaw Granite phase (411 ± 3 Ma, U–Pb titanite, Whalen 1993) of the Pokiok Batholith. Presently, the cusp of the granodioritic stock at Lake George lies about 350 m at depth below the present erosional level. Cordierite and biotite isograds delineated by Scratch *et al.* (1984) outline symmetrical contact metamorphism and overprinting metasomatism (W–Mo–Au) associated with this high-level stock. The contact metasomatic mineralized system and associated granodiorite is then cut by the Au-bearing polymetallic and the main antimony vein system (Morrissy and Ruitenberg 1980; Procyshyn and Morrissy 1990).

Au–W–Mo SKARN- AND VEIN-STYLE MINERALIZATION

Lake George contains gold mineralization described as skarn and stockwork veins associated with scheelite–molybdenite mineralization spatially and temporally related to the cupola region of the granodiorite (Seal II *et al.* 1988; Procyshyn and Morrissy 1990; Ruitenberg *et al.* 1990; Caron 1996). Stockwork mineralization extends into the upper parts of the cupola, indicating that the mineralizing episode is either synchronous with granodiorite emplacement or postdates it. Seal II *et al.* (1988) report a K–Ar age from a Stage II–III hydrothermal muscovite (411 ± 8 and 413 ± 8 Ma), which is coeval with the age of the Lake George Granodiorite. The Au–W–Mo mineralization is generally confined to the contact aureole (within the biotite zone) of the granodiorite stock. Seal II *et al.* (1987, 1988) documented convincing evidence that

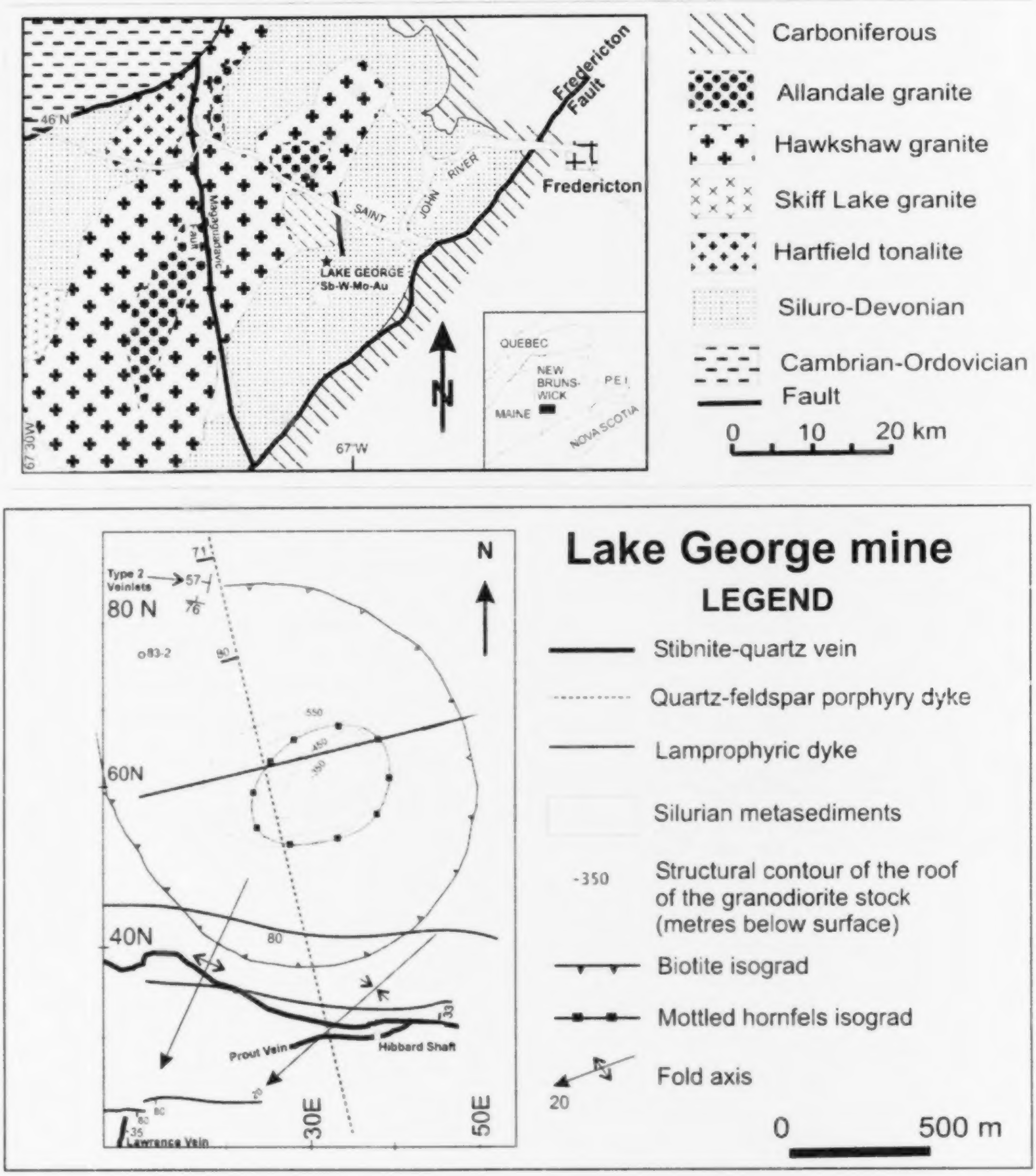

Figure 1. Location and general geology of the Lake George antimony mine, New Brunswick (modified after Seal II *et al.* 1988).

there are three stages of W–Mo mineralization (Type Ia, b, c) bracketing the emplacement of the quartz–feldspar porphyry and lamprophyre dykes; further work needs to be done to confirm that some of these veins (Type Ia) predate the lamprophyric dykes.

Irregular fracture-fill stockwork quartz–carbonate veining with distinct well-developed pyrite–arsenopyrite (± loellingite) hydrothermal alteration halos (vein mantled by blue–grey, then yellow–orange buff, and

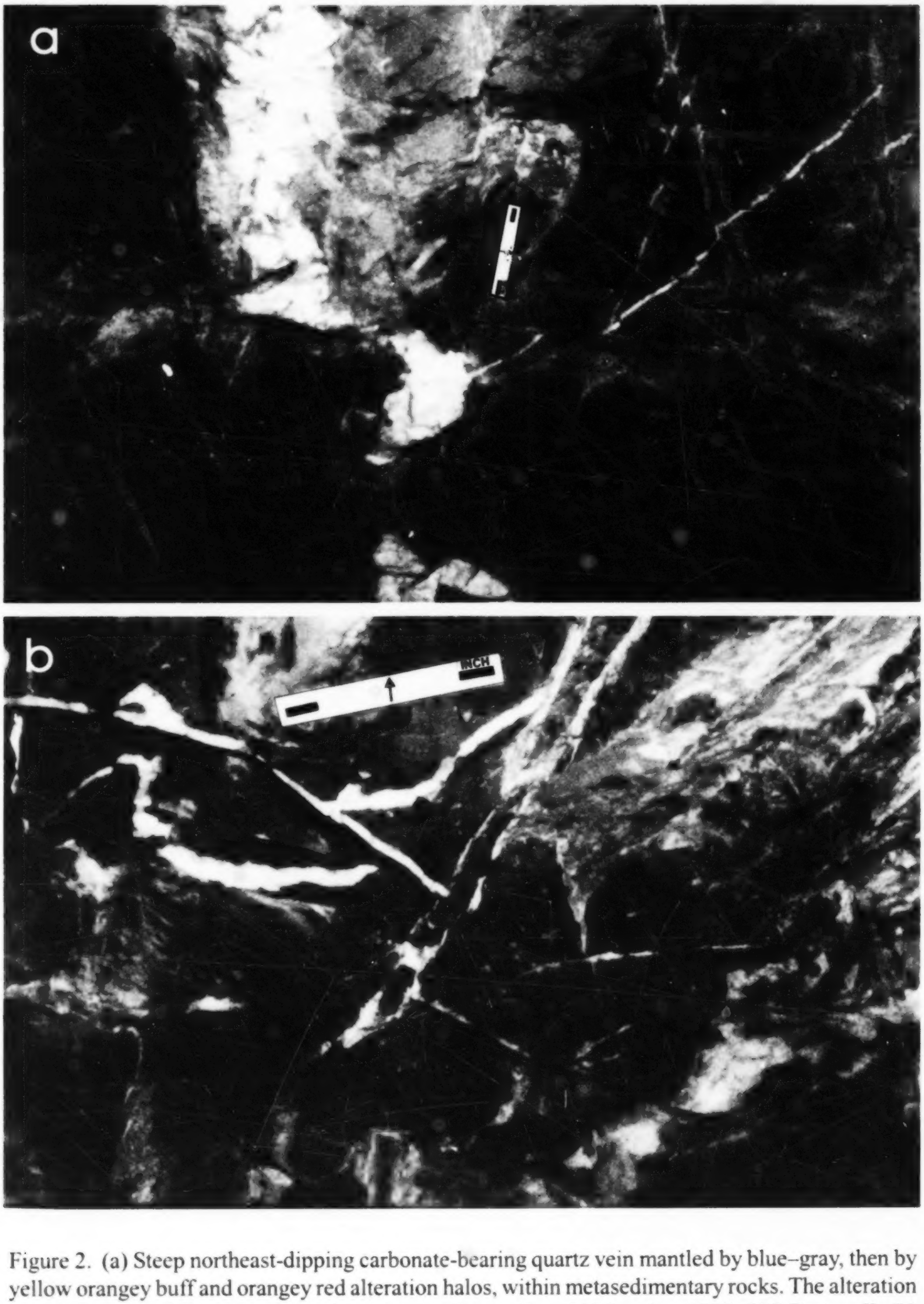

Figure 2. (a) Steep northeast-dipping carbonate-bearing quartz vein mantled by blue–gray, then by yellow orangey buff and orangey red alteration halos, within metasedimentary rocks. The alteration resembles the gold-bearing alteration systems. Located on 850 level at 1305, 275 East wall. (b) Shallow west-dipping vein is cut by steep southeast vein. Grey zone (middle right) has molybdenite. Located on 850 level at Survey Point 1305 (54 S). Photos by Angela Roy.

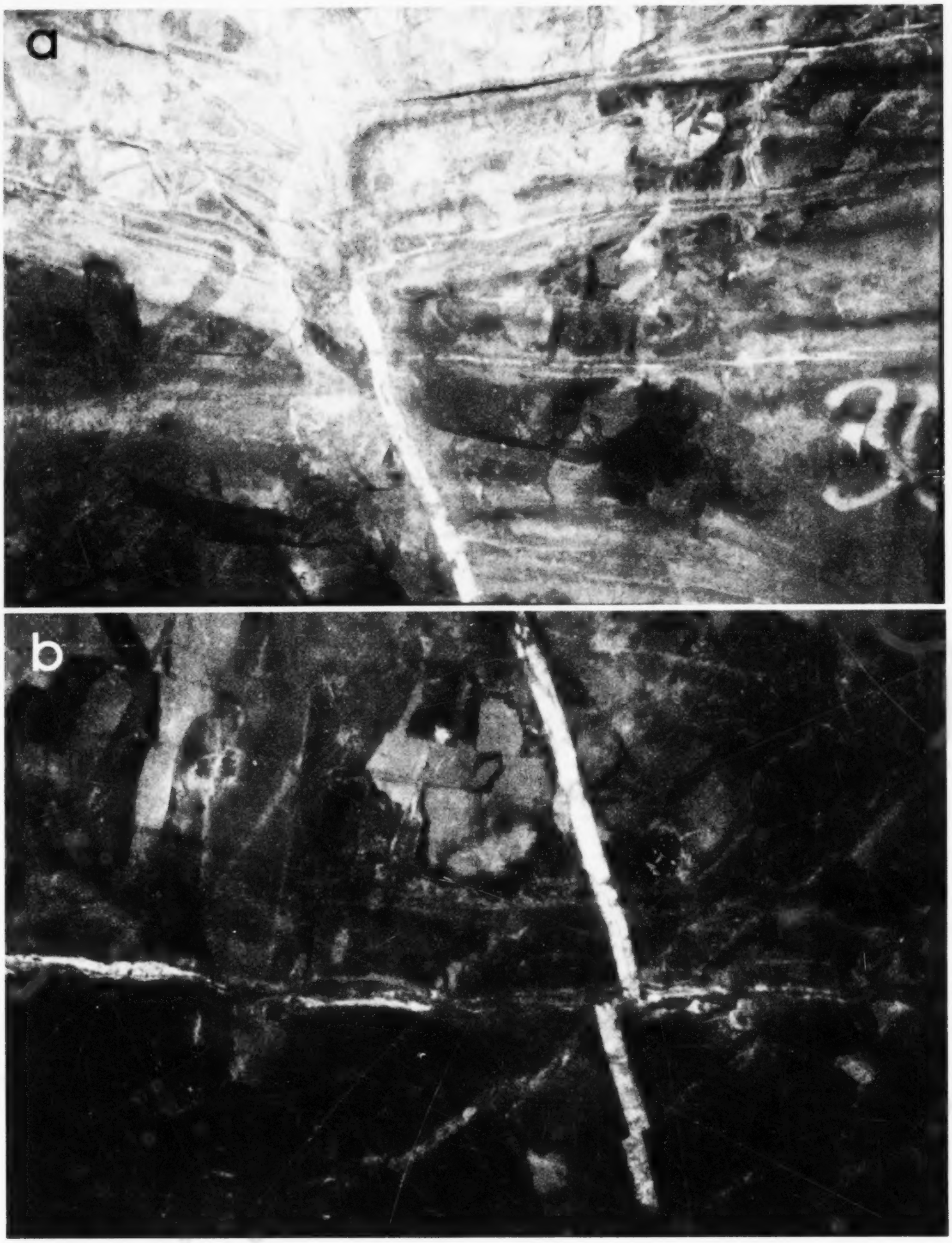

Figure 3. (a) Box work veins which merge with steeply dipping 3 cm wide molybdenite-bearing quartz vein (upper wall). (b) Steeply dipping molybdenite-bearing quartz vein is offset (centimetres) by horizontal carbonate-bearing fault with mantling alteration zone. Located in the gold room (26 W) South wall. Photos by Angela Roy.

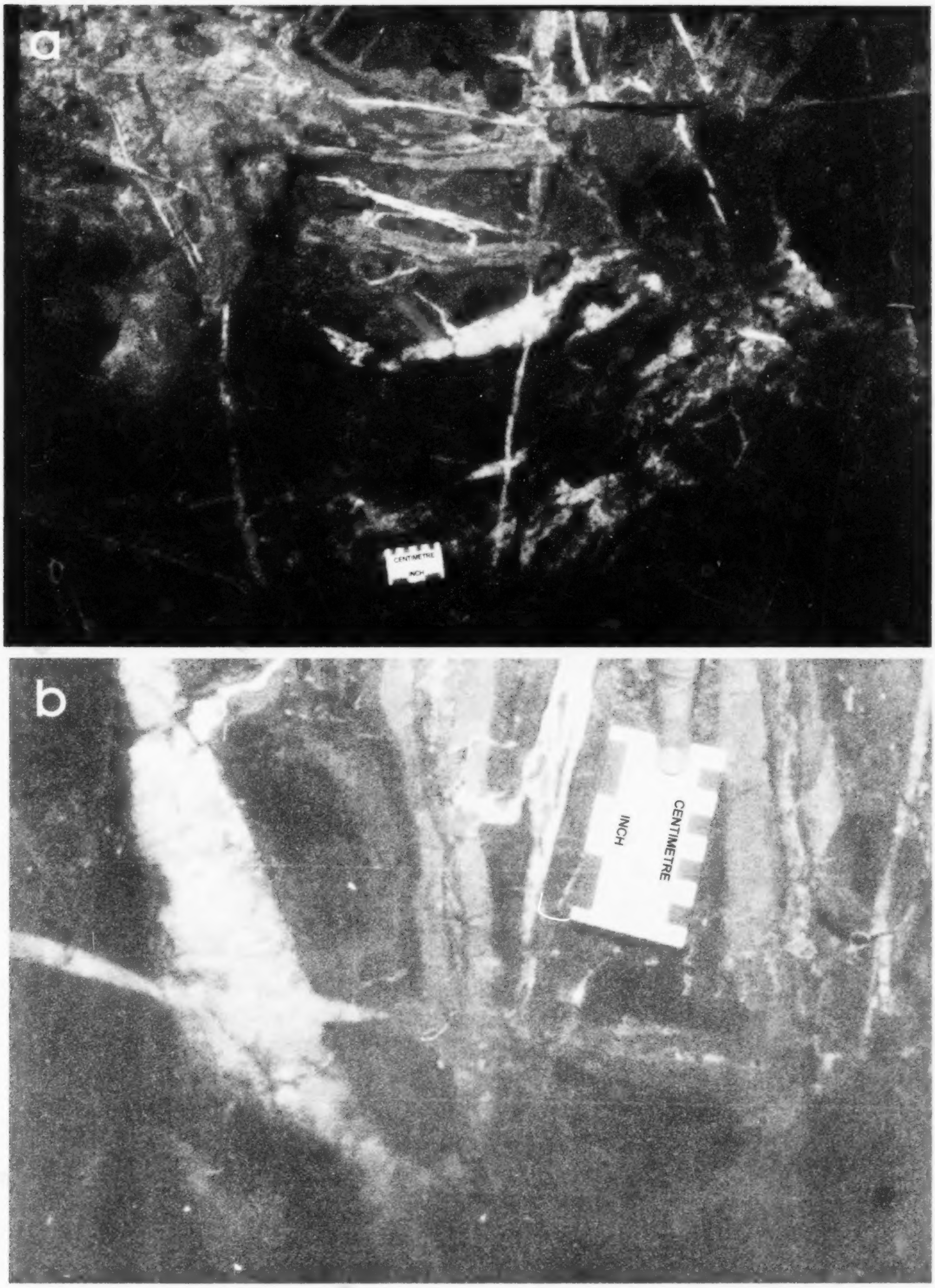

Figure 4. (a) Gold-bearing grey alteration zones mantling carbonate-rich fracture-filled veins with stockwork quartz veins of uncertain paragenesis. (b) Close-up of (a) showing quartz veins that seem to merge with gold-bearing carbonate veins with grey selvage. Located in the gold room (47 E) North wall. Photos by Angela Roy.

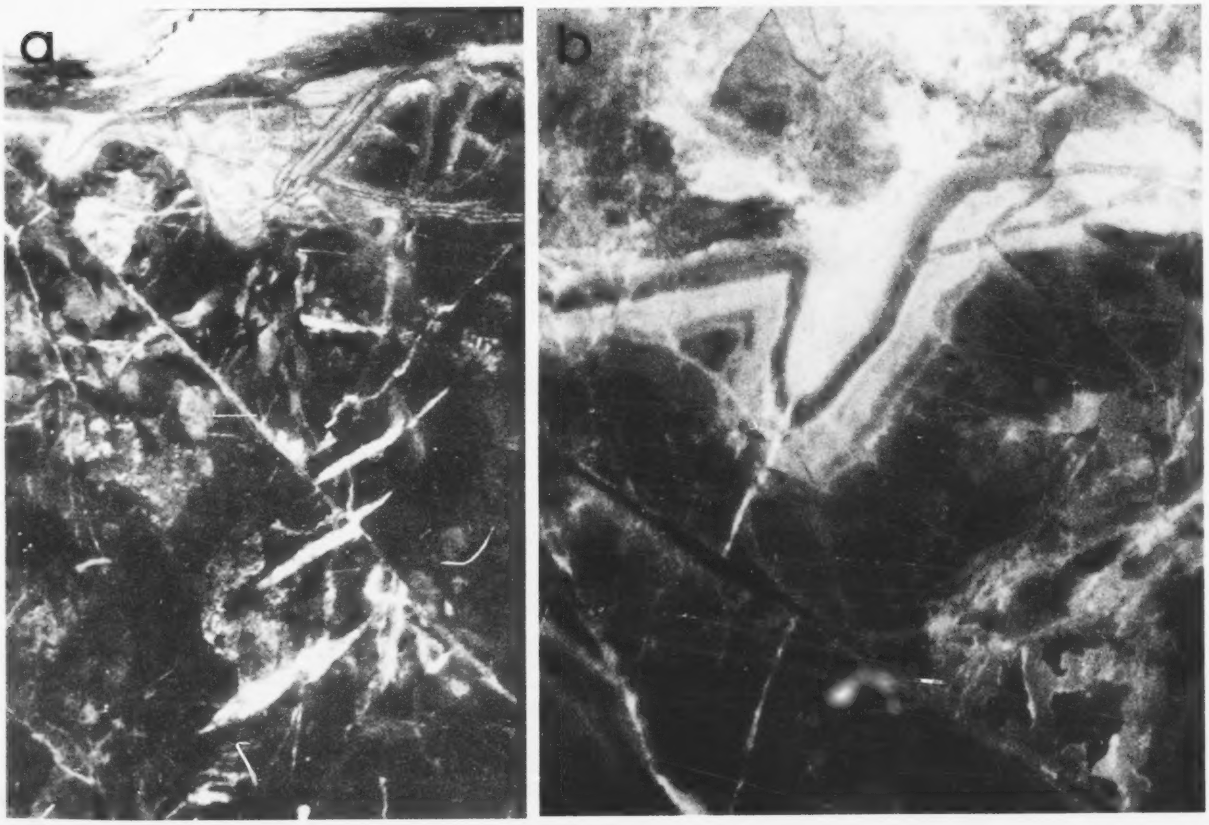

Figure 5. (a) Short en echelon, quartz-rich gash veins with gold-bearing, carbonate-rich veins with grey zoned alteration (top; approx. 1 m across). (b) Close-up of zoned alteration in (a), which is typical of gold-bearing areas. Located in the gold room (41 E) South wall (approx. 30 cm across). Photos by Angela Roy.

then orangish red alteration halos, see Figures 2, 3a, 4a, 5a, 6a, 7) has been noted in the gold drift (850 level) and within drill holes on the mine property (Morrissy 1991a, b; Caron 1996). The dilatant nature of these sulphide–quartz–carbonate veins is reminiscent of a hydrofracture vein network. The veins contain fibrous mineral growths, although they are locally recrystallized (subgrained), especially if subjected to deformation. These grey to orangish buff alteration zones reflect varying proportions of very fine-grained pyrite, arsenopyrite, carbonate, and fine-grained muscovite with intergrown rutile (see Caron 1996). In many cases, these replacement zones preserve the earlier tectonic fabric, i.e., are not recrystallized hydrothermally or always annealed. The molybdenite-bearing quartz veins seem to merge with the gold-bearing alteration system (Figures 3a, 4a, 5a, 6a); however, the same vein can be offset by a subhorizontal, later carbonate-bearing veins (Figures 3b, 5b, 6b) that resembles gold-bearing alteration zones. A close-up of a small dextral offset shows that the late vein is brittle with a lower degree of grey alteration on the selvage (Figure 8a). In Figures 3a and 3b, it is evident that for at least some molybdenite-bearing quartz veins, the alteration zone mantling these veins is much more restricted than the alteration episode associated with gold mineralization. Irregular to nodular calc-silicate pods are overprinted by the zoned gold-bearing vein systems (Figure 7). The gold-related vein and alteration system is cut by the large shallowly dipping, antimony–quartz vein system (Figure 8b) that also has an alteration halo. However, zoned alteration

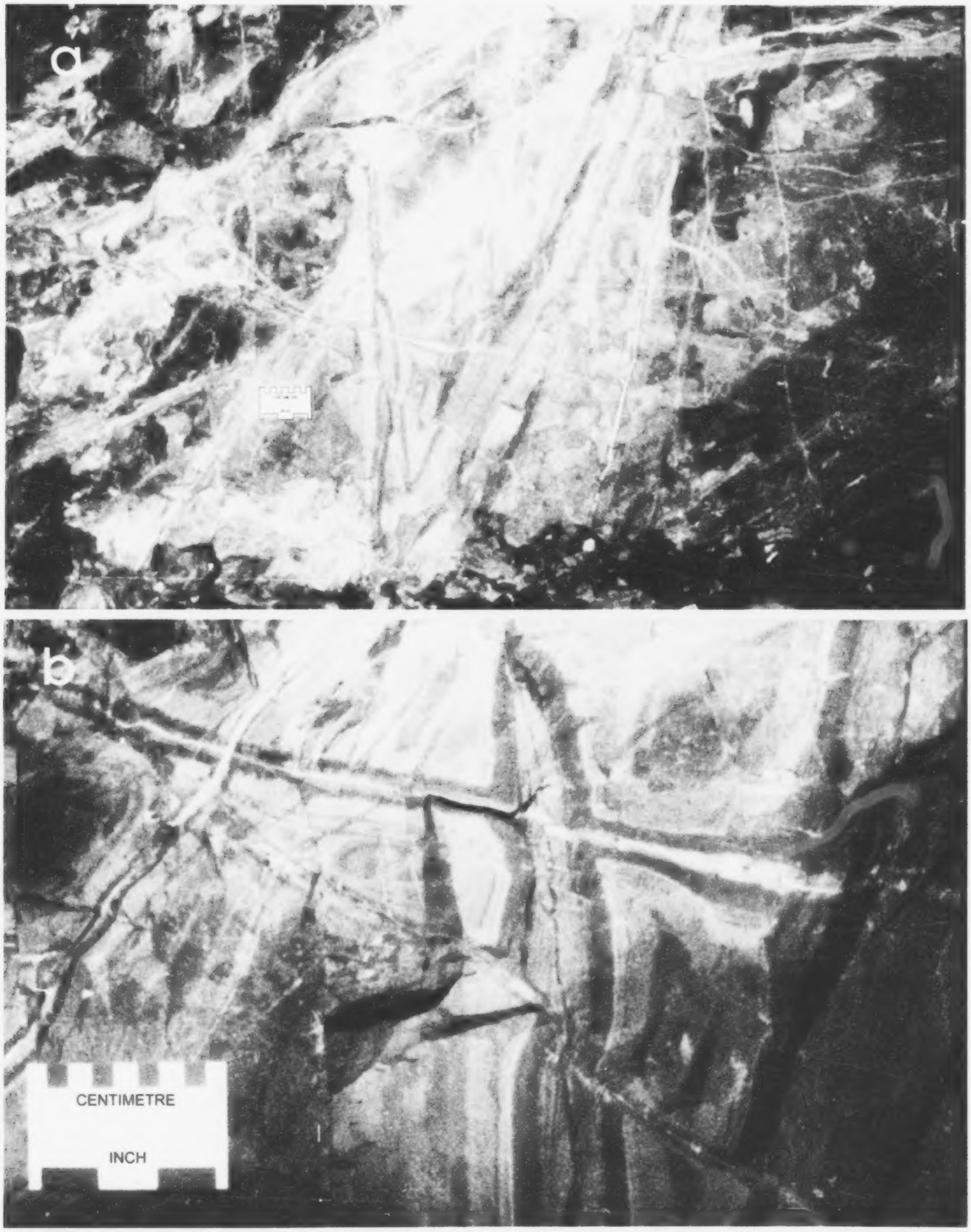

Figure 6. (a) Gold-bearing alteration zone with nested veins cored by carbonate and quartz. (b) Close-up of (a) showing discretely zoned alteration around veins of various orientations. Only very minor displacement occurs across these stockwork veins. Located in the gold room (25 E) North wall. Photos by Angela Roy.

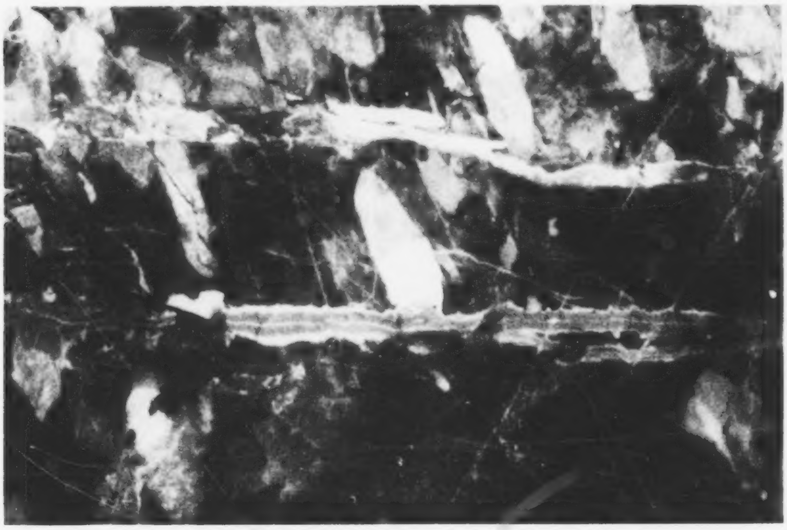

Figure 7. Oval calc-silicate nodules (10 cm long) oriented parallel to bedding, cut by subhorizonal zoned gold-bearing hydrothermal veins. Located in gold drift (35 E) South wall (approx. 1 m across). Photo by Angela Roy.

associated with quartz–carbonate veins is not restricted to the gold drift/room, but has also been noted on the rest of the 850 level (Fig. 2), with minor shear displacements that have weaker degrees of alteration mantling them that may be cored by vein filling minerals.

As is discussed later, Caron (1996) has compared the alteration halos and found many gross similarities associated with the various mineralizing events discussed above. These similarities may indicate a continuum in the evolution from the Au–W–Mo to the Au–Sb system. The most significant gold mineralization is hosted within a hydrothermally altered stockwork and breccia zone that occurs 25 m above the hanging wall of the Hibbard stibnite vein on the 850 level. The genetic relationship of these quartz–carbonate-rich stockwork and breccia zones to the stibnite–quartz vein system is uncertain (see Caron 1996), although from the similarities in elemental association (see below), they seem to be related to the W–Mo contact metasomatic event. The close spatial relationship of the distinctive gold-bearing, sulphide–quartz–carbonate vein system in the hanging wall to the Hibbard antimony–quartz vein mineralization is important to consider. Negligible amounts of carbonate are present in the Hibbard vein; however, crustiform quartz lining the walls of the vein contains breccia-like fragments. These breccias may represent scaling of the wall rocks during seismic pumping events (Figure 9a). At least in some parts, it seems that the antimony vein is simply dilatant in character with minimal offset parallel to the vein across the lamprophyre dyke–sediment contact (Figure 10). In many other parts of the mine, the stibnite–quartz veins are brecciated (angular hydrothermal quartz and altered sediment clasts, Figure 9b) with stibnite remobilized into the matrix with recrystallized quartz. The tectonically brecciated stibnite–quartz veins (brittle) are also faulted, which locally complicates the mine geology and grade controls (Figure 11).

The exploration of the stockwork and breccia zone, described above, resulted as a follow-up on gold

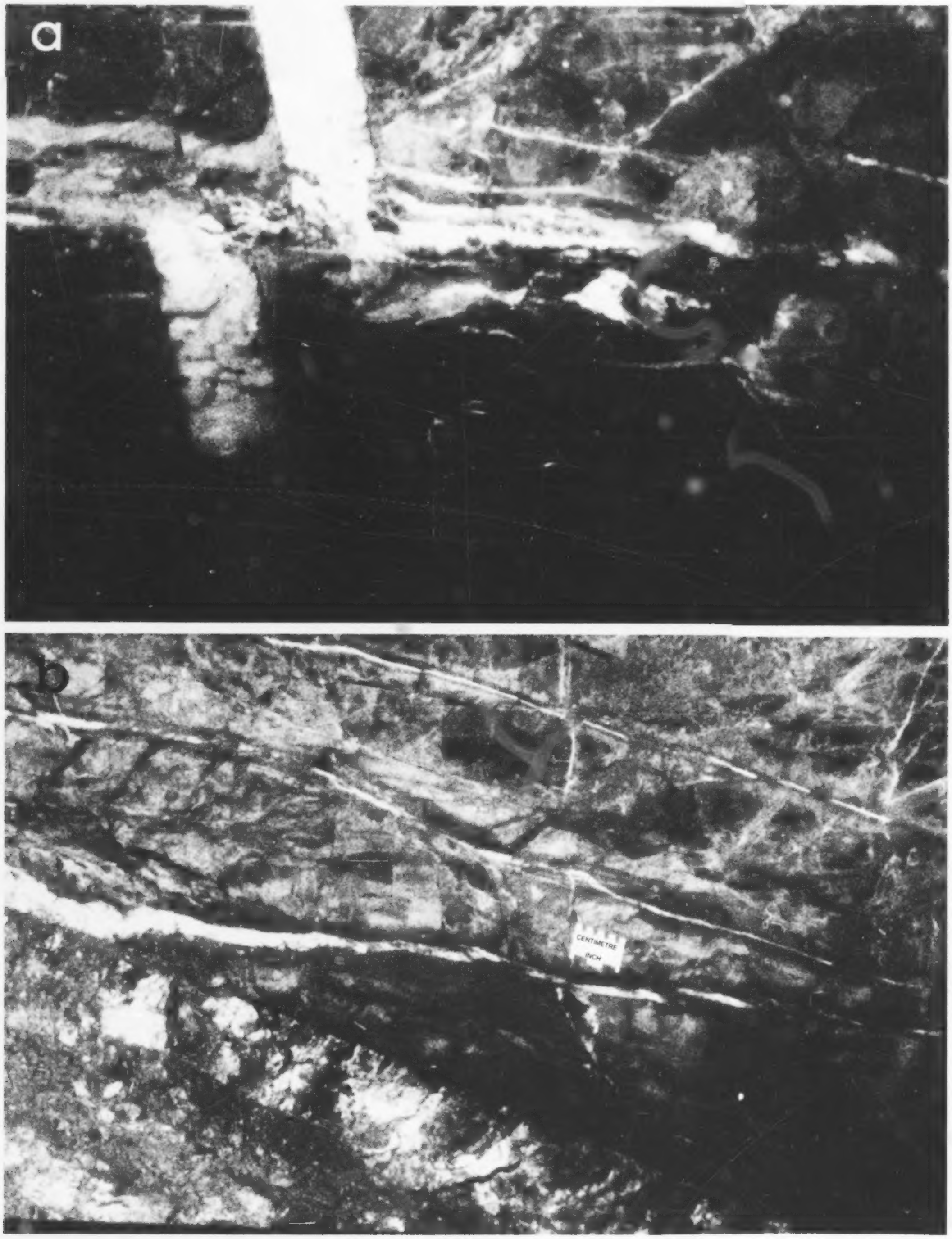

Figure 8. (a) Steeply dipping molybdenite-bearing quartz vein offset (centimetres) by horizontal carbonate-bearing fault with mantling alteration zone. Located in the gold room (26 W) South wall. (b) Gold-bearing carbonate veins (less than a few centimetres) with alteration selvages cut by wide shallowly dipping antimony–quartz Hibbard vein (> 1 m wide, bottom). Located on 850 level at Survey Point 877 (18 E) on West wall. Photos by Angela Roy.

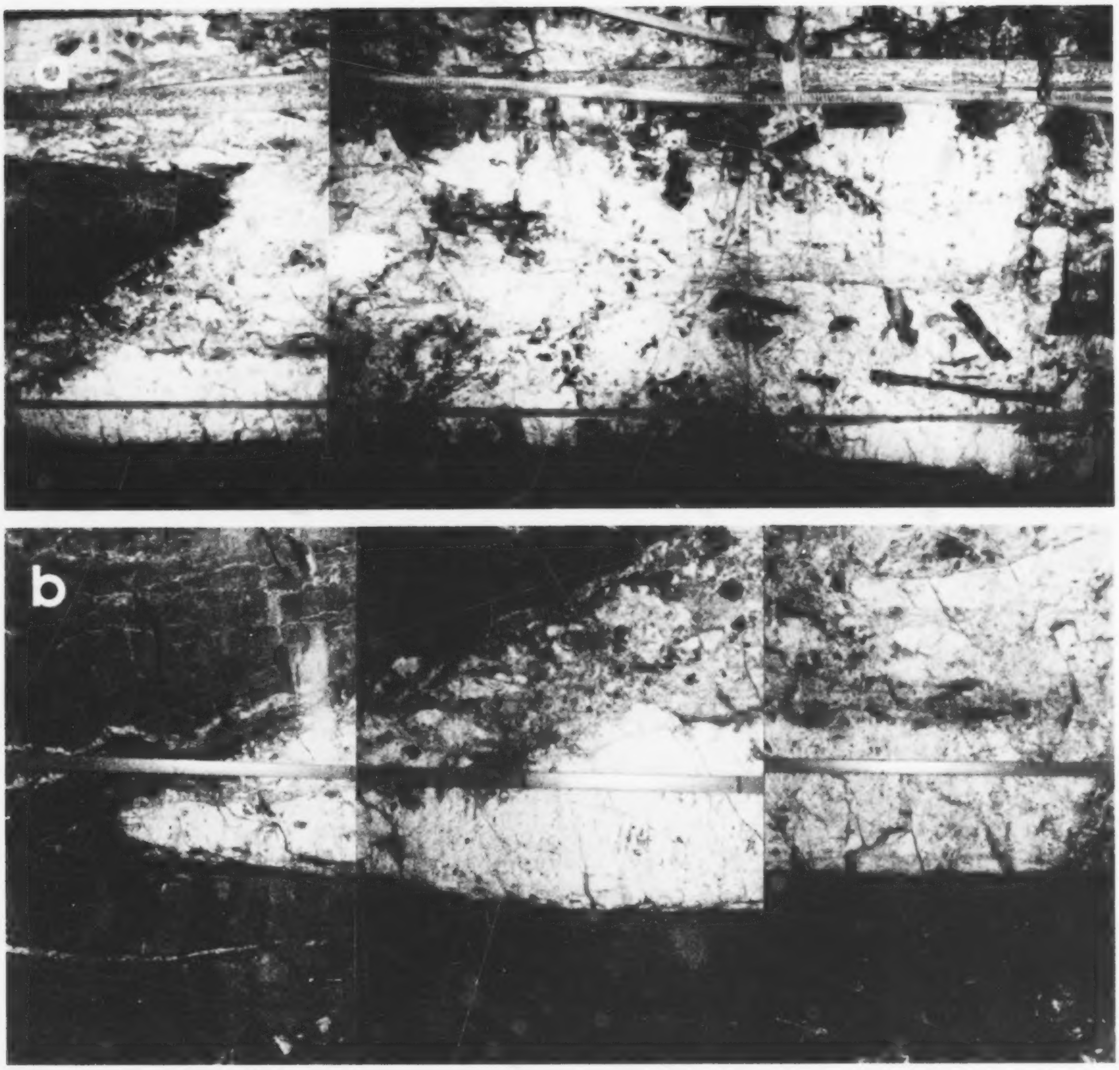

Figure 9. (a) Quartz–antimony breccia vein with vug hosted in metasedimentary rocks. Located on 850 level at Survey Point 876 (2 W) North wall. (b) Quartz–antimony vein (lens) with drusy crystals perpendicular to the wall and locally brecciated along upper margin with sulphide–quartz matrix. Located on 850 level at Survey Point 876 (5 to 11 W). Photos by Angela Roy.

assays from an earlier drill hole that returned 7.5 g/t Au over 2 m. Underground exploration delineated this gold-bearing structure, which gave an average 0.086 oz./ton (2.95 g/t) Au over a length of 86 ft. (26.2 m) with an average width of 9.7 ft. (2.96 m) (Morrissy 1991b). Up to 0.54 oz./ton (18.5 g/t) is reported in one particular sample (Morrissy 1991b). Arsenopyrite (70%), pyrite (25%), and minor (< 5%) rutile, titanite, pyrrhotite, stenbergite, tetrahedrite, stibnite, native antimony, chalcopyrite, berthierite, allemontite, and molybdenite were observed in a sample (87-203) of the gold-rich ore (Davison 1988). The association with molybdenite, negligible stibnite and native antimony suggests that this mineralizing episode is related to the earlier W–Mo mineralizing episodes. In that study, two very fine grains of native

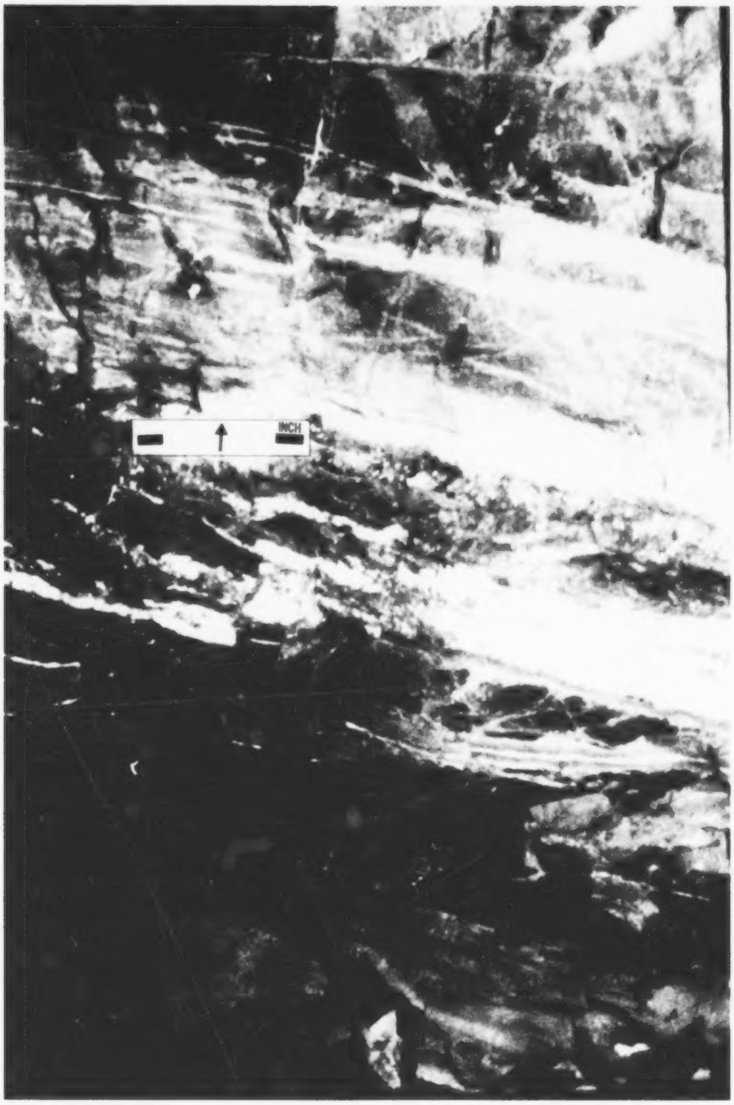

Figure 10. Shallow-dipping antimony vein cutting steep siltstone–lamprophyre contact. Located on 850 level at Survey Point 880 (27 W) on South wall. Photo by Angela Roy.

gold were observed in fractured arsenopyrite. Based on the rare occurrence of native gold, Davison (1988) suggested that much of the gold was submicroscopic within pyrite and arsenopyrite. Process testing of a pyrite- and arsenopyrite-rich sample of the gold-rich ore (10.0 g/t) yielded poor recoveries consistent with Davison's theory (Harris 1990).

As stated by previous researchers (Seal II *et al.* 1988; Procyshyn and Morrissy 1990; Ruitenberg *et al.* 1990), the close spatial and temporal relationship of the Au–W–Mo mineralization to the granodiorite along with high depositional temperatures associated with quartz and ore minerals obtained from fluid inclusion data in Type I and III mineralization (Scratch *et al.* 1984; Seal II *et al.* 1987), support a magmatic–

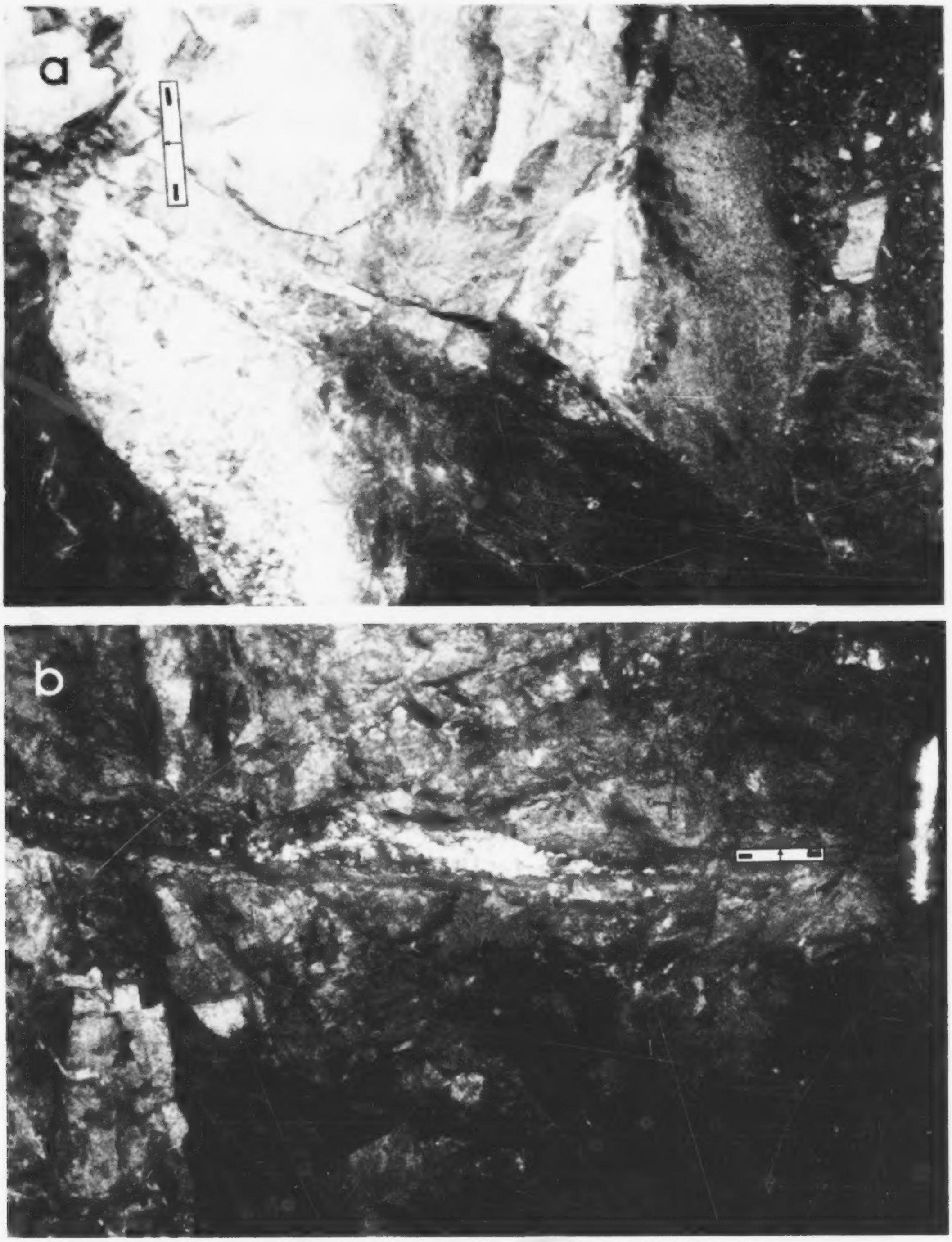

Figure 11. (a) Antimony–quartz vein in dextral offset, with angular siltstone fragments in the vein. Located on 850 level at Survey Point 771 (20 N) North wall. (b) Fault gouge with quartz–antimony vein and carbonate-rich core. Located on 850 level at Survey Point 775 (33-39W) South wall. Black bar on scale is 1 inch (2.5 cm). Photos by Angela Roy.

hydrothermal source. This convinced Yang *et al.* (2002a, b) that continued vapour exsolution associated with crystallization of the pluton during emplacement and cooling was responsible for the contact metasomatic deposit.

GOLD-BEARING ANTIMONY VEIN SYSTEM

The anastomosing and locally undulating stibnite-rich veins (Prout and Hibbard) are typically less than 2 m wide, strike east–west and dip shallowly (33°) to the north. A north-northeast-trending, shallowly east-dipping vein (Lawrence) is located on the southwest end of the mine site. This antimony vein cross cuts the granodiorite porphyry and has been dated by K–Ar (phyllic alteration) at 417 ± 8 Ma (Seal II *et al.* 1988) thus indicating a problem with the ages (i.e., slightly too old), although noting that the mineralization is closely related to the intermediate magmatism in the region. Details of the grade and tonnage figures for the antimony deposit are given by Procyshyn and Morrissy (1990).

The gold grades in the stibnite-rich veins (based on only a few analyses) are relatively low (110 ppb, n = 15; Scratch *et al.* 1984), but significant variations are known. Pyrite (72%), arsenopyrite (15%), pyrrhotite (4%), marcasite (3%), stibnite (2.5%), native antimony (1%), and less than 1% for magnetite–ilmenite, hematite–geothite, chalcopyrite, tetrahedrite, sphalerite, berthierite, and sternbergite are the phases recognized in the mill tailings sample (Davison 1988). No native gold was observed in the tailings sample; therefore, it was inferred that the gold was hosted in arsenopyrite. In addition to these phases, Abbott and Watson (1975) and Kaiman *et al.* (1980) identified chalcostibnite, plagionite, fuloppite, bournonite, cubanite, and stibivanite in the antimony ore. An assay of the mill tailings containing pyrite, with minor arsenopyrite, pyrrhotite, sphalerite, and stibnite, yielded 0.35 g/t Au. This sample was gravity concentrated (3200 %) to 11.2 g/t Au (Harris 1990) for metallurgical testing. Also, seven tailings assays for Au, As, Sb, W (INAA – XRAL) by Alain Caron yielded 334 ± 147 ppb, 4286 ± 553 ppm, 5057 ± 1218 ppm, 38 ± 7 ppm, respectively. Process testing confirmed that gold in the tailings was refractory and occurred as submicroscopic inclusions or in solid solution in pyrite and (or) arsenopyrite (Harris 1990). Based on a preliminary examination of these ores petrographically, and using electron microprobe microanalysis (EPMA) and scanning electron microscopy (SEM) at the University of New Brunswick, no native gold was found in a sample from the antimony vein. Therefore, gold seems to be tied up in other sulphides like pyrite and arsenopyrite, although solution in stibnite and native antimony cannot be ruled out. If gold was in solution with native antimony (very minor), then gold grades might be higher in the western parts of the antimony vein, where native antimony is more abundant.

Using geochemical data from Scratch *et al.* (1984), there is a significant correlation between Sb and As in the vein (Figure 12), although gold content varies independently of Sb (r = 0.03) and As (r = -0.11) content of the stibnite vein. Overall, the lack of association of gold with Sb and As is consistent with the relatively high abundance of pyrite in the antimony deposit compared to arsenopyrite.

GEOCHEMICAL CONSIDERATIONS

Re-examination of selected geochemical data from the Lake George mine (AR-series; Caron 1996) is presented to enhance our understanding of the petrogenetic link between gold and the various styles of mineralization. Geochemical analyses of the samples, for which site locations and brief descriptions (by Angela Roy) are included in the appendix, were performed by XRAL (Don Mills, Ontario). The calculated average geochemical data for wacke–slate, altered wacke–slate, granodiorite, and altered granodiorite

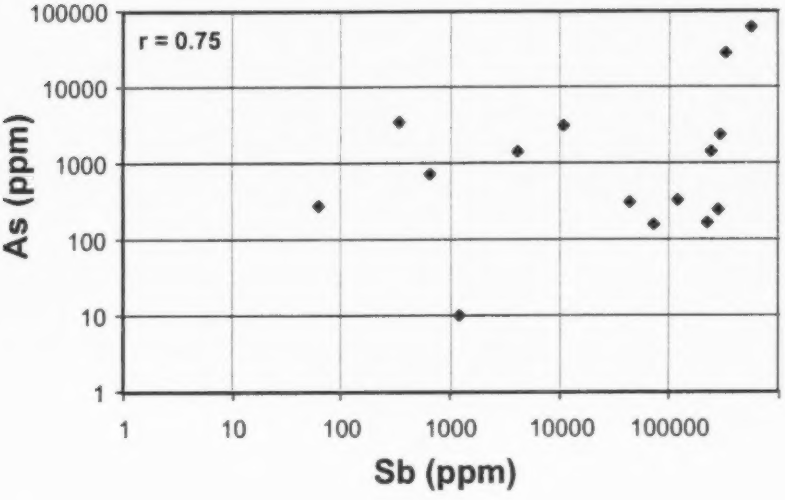

Figure 12. Sb versus As content of the stibnite-rich veins at Lake George (data from Scratch *et al.* 1984).

from the samples subdivided by Caron (1996) are presented in Table 1. The detailed mass-balance-based alteration analysis used by Caron (1996) is superior to other techniques, although only selected data were presented. Therefore, a more general analytical approach is presented here using the whole-rock compositional data coupled with general information of the least-altered granodiorite (Yang *et al.* 2002a) and least-altered sedimentary rocks (slates and greywacke) (Scratch *et al.* 1984).

The average composition of the least-altered granodiorite is very similar to the average of 10 least-altered Lake George samples presented by Yang *et al.* (2002a), although some of the mineralizing elements are higher likely due to cryptic propylitic alteration. The altered granodiorite has higher contents of Au, As, Sb, W, B, Rb, K_2O, and Zn with lower Na_2O, CaO, Mn, and Sr (Table 1) consistent with mass-balance analysis (see Caron 1996). These geochemical variations are due to sericitic alteration of feldspars in the cupola, which are inferred to be related to antimony vein development. Morrissy and Ruitenberg (1980), Watson (1981), and Scratch *et al.* (1984) described the alteration in detail mantling the large antimony vein system, although this was prior to the recognition of an earlier Au–W–Mo system. Although Caron (1996) infers that these granodiorite samples were sericitized by the fluids forming the antimony vein, the high Au correlation with As, Mo, and W relative to Sb (Figure 13) supports the proposal that some of this alteration was associated with the earlier style of mineralization.

It is apparent from Table 1 that most of the metasedimentary rocks are significantly mineralized even though they were not recognized as hydrothermally altered in the tabulation made by Caron (1996). They are enriched in Au, As, W, Mo, with minor Sb; therefore, it is possible that much of the gold mineralization must be associated with finely disseminated mineralization with cryptic alteration. The obviously argillic to sericitically altered samples of metasedimentary rock seem to have slightly less mineralization than these presumably cryptically mineralized slate and wacke samples. Unlike the granodiorite, the bulk composition of the sedimentary rocks is highly variable (see Scratch *et al.* 1984); therefore, it is more difficult to ascertain the geochemical effects of gold-mineralization-related alteration. However, Caron (1996) noted that As, Sb, Rb, and LOI were enriched in the metasedimentary rocks, whereas Na_2O, CaO,

Table 1. Average Whole-rock Composition of Rocks at the Lake George Mine

Type	Sediments	SD	Altered Sediments	SD	Granodiorite	SD	Altered Granodiorite	SD
n	24		23		5		5	
wt. %								
SiO_2	54.7	21.9	68.9	7.5	68.1	2.1	68.7	2.0
Al_2O_3	12.99	2.72	13.07	2.89	14.88	0.64	15.76	1.19
CaO	6.17	5.50	1.94	1.63	2.44	1.01	0.99	0.48
MgO	3.31	2.22	1.85	1.11	1.10	0.17	0.88	0.24
Na_2O	1.01	1.31	0.70	0.97	3.29	0.33	0.55	0.92
K_2O	3.70	1.38	3.09	1.26	2.51	0.21	4.27	0.74
$Fe_2O_3^T$	4.99	1.78	4.74	1.97	3.50	0.22	3.15	0.24
MnO	0.12	0.10	0.04	0.03	0.11	0.03	0.05	0.03
TiO_2	0.76	0.13	0.75	0.11	0.54	0.11	0.60	0.08
P_2O_5	0.14	0.05	0.12	0.02	0.11	0.02	0.13	0.02
LOI	7.3	5.5	3.7	1.8	3.7	0.7	4.4	1.1
Total	95.2		98.9		100.3		99.5	
ppm								
Au (ppb)	3961	4298	239	357	25	15	291	411
B	114	72	140	154	32	6	148	145
Sc	12	3	12	5	7	1	8	2
V	105	23	107	37	65	19	68	9
Co	13	2	14	5	8	2	8	2
Ni	54	9	68	28	20	3	20	3
Cu	18	8	35	33	51	26	18	6
Zn	46	29	84	32	57	10	62	17
As	17718	16446	4524	9101	340	550	5450	8884
Mo	47	186	2	3	2	2	3	2
Sb	133	172	515	1419	85	32	169	214
Cs	8.1	2.7	10.1	5.1	7.1	1.4	9.8	4.1
La	38.0	8.3	35.4	6.8	29.7	3.3	30.1	5.0
Ce	64.0	19.0	65.8	13.5	55.2	6.9	55.0	7.6
Nd	27.71	7.17	28.09	6.49	22.40	3.13	22.00	2.83
Sm	6.11	1.93	5.31	1.38	4.13	0.65	4.31	0.58
Eu	1.65	0.60	1.16	0.39	0.96	0.08	0.95	0.28
Tb	0.82	1.12	0.69	0.22	0.70	0.10	0.68	0.08
Yb	1.70	0.72	2.40	0.72	2.26	0.11	2.31	0.28
Lu	0.23	0.13	0.35	0.12	0.33	0.01	0.34	0.04
Hf	9.8	3.8	7.6	3.2	5.2	0.7	5.3	1.1
W	107	103	30	35	21	18	47	17
Pb	7	6	8	5	13	5	9	6
Bi	1.6	1.5	2.2	3.0	1.9	1.2	1.0	0.2
Th	9.4	1.8	8.7	2.1	14.6	3.6	14.6	1.9
U	2.3	1.0	2.7	0.8	7.4	2.0	7.0	1.5
Cr	106	23	114	28	22	3	21	3
Rb	146	34	148	67	127	15	200	31
Sr	200	107	104	94	207	60	76	39
Y	33	12	31	11	28	9	31	9
Zr	348	123	303	121	165	8	180	31
Nb	20	7	17	9	20	11	16	7
Ba	361	88	317	107	307	39	339	80

Note: SD – standard deviation; n – number of samples used in tabulated average. Calculated from data in Caron (1996) Appendix 2.

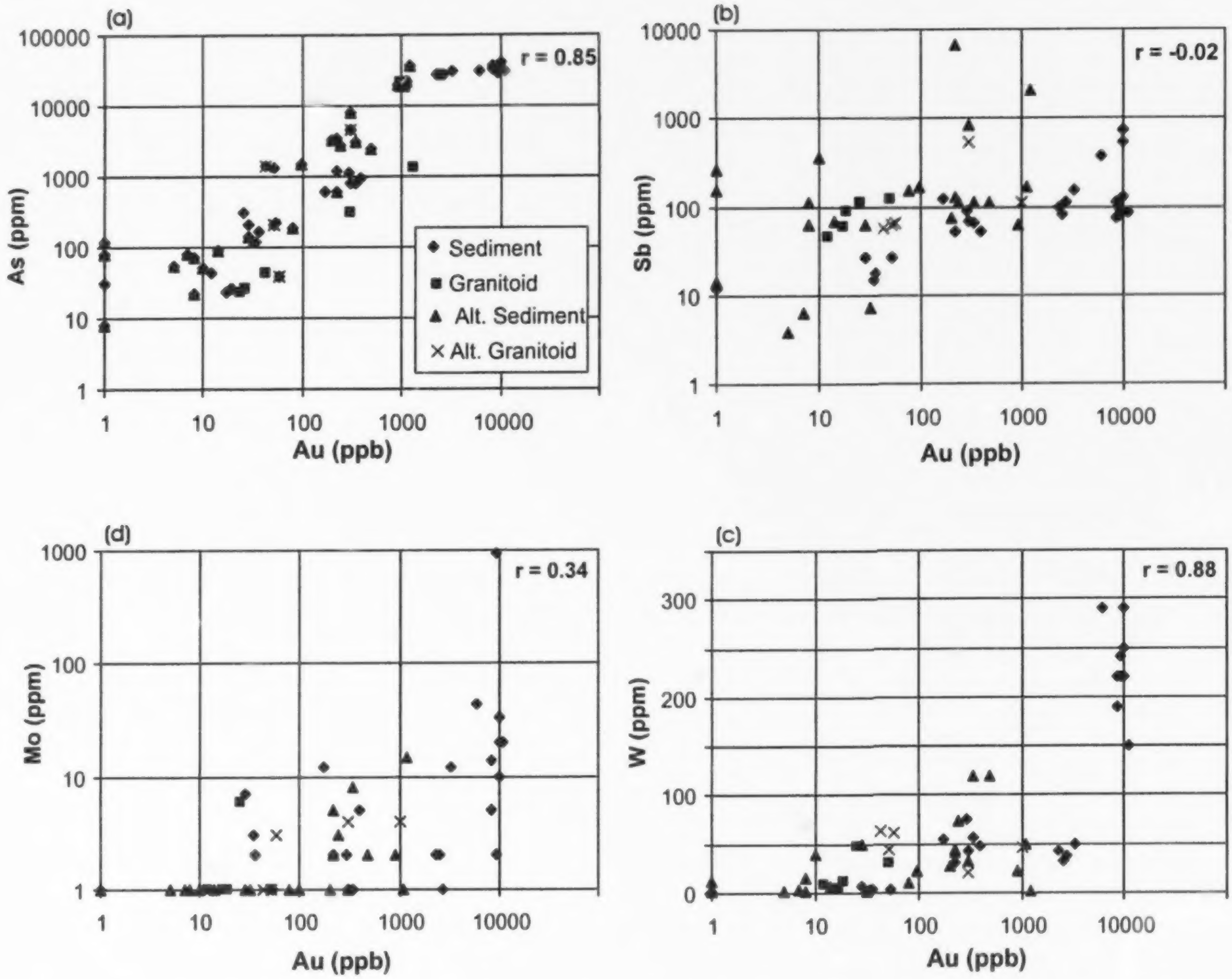

Figure 13. As (a), Sb (b), Mo (c), and W (d) versus Au content of sedimentary rocks, granitoid rocks, and their altered equivalents at the Lake George deposit. Geochemical data is from Caron (1996). Abbreviation: r – Pearson Product correlation coefficient.

MgO, MnO, Sr, and Zn are leached from the rocks that experienced sericitic to argillic alteration associated with the gold zone (near 850 foot level).

Based on the compositions (Figure 14), it is apparent that the samples with the highest Au content (gold drift) have high $Fe_2O_3^T$, K_2O, and CaO and very low SiO_2. The association of greater gold abundances with high $Fe_2O_3^T$ may be explained in terms of gold deposition through sulphur fixation reactions based on intrinsic $Fe_2O_3^T$ contents of the various protoliths (granodiorite: 3.50 wt. %; sediments: 4.99 wt. %; lamprophyre: 8.30 wt. % (Lentz *et al.* 2002)). Interestingly, the Al_2O_3 is consistently high (> 10 wt.%) in the nine samples with notably high gold (> 5000 ppb). Therefore, mass change should not be a significant factor in sulphide-bearing skarn, phyllic (sericitic), or argillic (grey) replacement zones (< 25% volume increase), except the related quartz–carbonate–sulphide dilatent veining itself. This is consistent with the

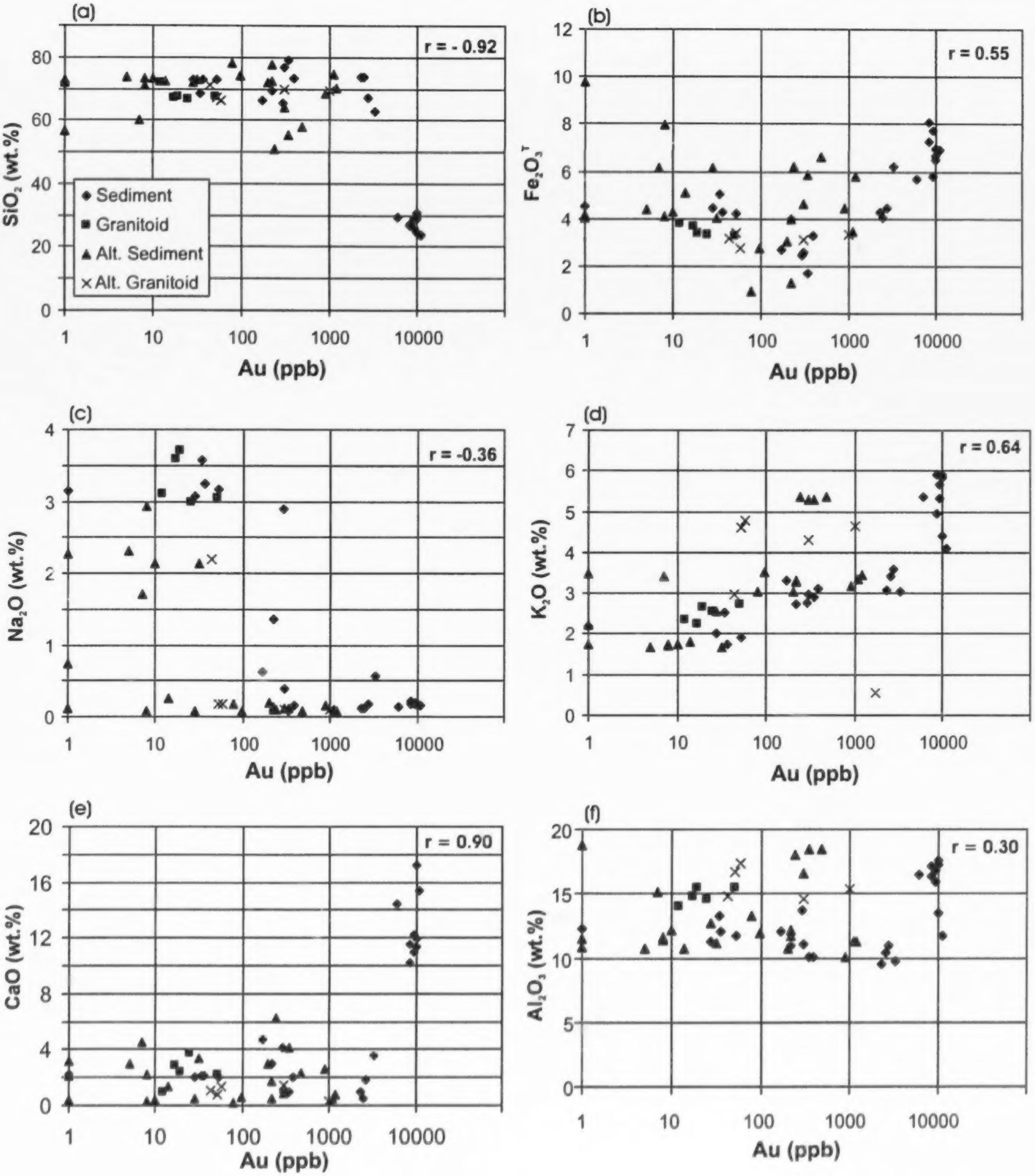

Figure 14. SiO_2 (a), $Fe_2O_3^T$ (b), Na_2O (c), K_2O (d), CaO (e), and Al_2O_3 (f) versus Au content of sedimentary rocks, granitoid rocks, and their altered equivalents at the Lake George deposit. Geochemical data is from Caron (1996).

mass-balance observations on the grey and sericitic alteration zones, characterized by addition of Fe, Ca, As, Sb, W with carbonate and removal of Na, Mg, and silica (suturing of quartz).

SYNOPSIS

Overall, considerable petrochemical, geochronological, and isotopic work coupled with a study of the spatial analysis of the mineralizing system needs to be done to explain these preliminary geochemical observations so as to ascertain the controls on gold mineralization. In particular, gold analyses of various sulphides in the breccia, stockwork, disseminated, and microveinlet styles of mineralization (Type I & II) in the contact aureole of the granodioritic intrusion at Lake George and within the stibnite–quartz vein (Type III), are required to link these analyses with the complex fluid history that is partly described by previous authors. Although limited in scope, this preliminary geochemical study concurs with the proposal put forth by Seal II *et al.* (1988), that the entire metallogenic suite found at the Lake George deposit is of magmatic–hydrothermal derivation.

ACKNOWLEDGMENTS

APOCAN, in particular Wayne Marshall, allowed us access to the information and drill core on the mine site. Natural Sciences and Engineering Research Council of Canada provided funding for this project. Discussions with Les Fyffe and Malcolm McLeod helped with our understanding of the local geology and structure. Editing of this manuscript by Malcolm McLeod is gratefully acknowledged.

REFERENCES

ABBOTT, D. and WATSON, D. 1975. Mineralogy of the Lake George antimony deposit, New Brunswick. Canadian Mining and Metallurgy Bulletin, **68**: 111–113.

CARON, A. 1996. Geology of the Pokiok Batholith aureole, with emphasis on the Lake George Mine, York County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy, Geoscience Report 94-2, 91 p.

CHI, G., WATTERS, S., FYFFE, L.R., MCLEOD, M.J., LENTZ, D.R., YANG, X., THORNE, K., CASTONGUAY, S., DAVIS, W., TREMBLAY, A., DUBÉ, B., SAVARD, M.M., JOHNSON, S., LAUZIÈRE, K., RENNICK, P., and HOY, D. 2001. Metallogeny of intrusion-related gold systems in southwestern New Brunswick. *In* Abstracts, 2001: 26th Annual Review of Activities. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 2001-1, pp. 15–16.

DAVISON, J.G. 1988. Mineralogical investigation of several gold-bearing ores. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File Report 88-17, 76 p.

FYFFE, L.R. and FRICKER, A. 1987. Tectonostratigraphic terrane analysis of New Brunswick. Maritime Sediments and Atlantic Geology, **23**: 113–122.

HARRIS, R.D. 1990. Processing of selected New Brunswick gold resources. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File Report 90-3, 34 p.

KAIMAN, S., HARRIS, D.C., and DUTRIZAC, J.E. 1980. Stibivanite, a new mineral from the Lake George antimony deposit, New Brunswick. Canadian Mineralogist, **18**: 329–332.

LANG, J.R. and BAKER, T. 2001. Intrusion-related gold systems: the present level of understanding. Mineralium Deposita, v. 36, p. 477-489.

LANG, J.R., BAKER, T., HART, C.J., and MORTENSEN, J.K. 2000. An exploration model for intrusion-related gold systems. SEG Newsletter, No. 40, pp. 1–15.

LENTZ, D.R. In press. Multi-element Instrumental Neutron Activation Analysis of drill core from the Lake George mine, York County, New Brunswick. New Brunswick Department of Natural Resources and Energy; Mineral, Policy and Planning Division, Open File.

LENTZ, D.R., THORNE, K.G., YANG, K.G., and ADAMS, M. 2002. Calc-alkaline lamprophyre dykes of the Lake George antimony deposit, New Brunswick: petrochemical characteristics and implications for gold mineralization. *In* Current Research 2001. (this volume)

MCLEOD, M.J., JOHNSON, S.C., and RUITENBERG, A.A. 1994. Geological map of the southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources, Map NR-5 (scale: 1:250 000).

MCLEOD, M.J. and MCCUTCHEON, S.R. 2000. Gold environments in New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division. Plate 2000-28.

MORRISSY, C.J. 1991a. Further characterization of drill core from the Lake George mine, York County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources, Open File Report 91-8, 74 p.

MORRISSY, C.J. 1991b. Gold assessment at the Lake George mine, York County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources, Open File Report 91-1, 22 p.

MORRISSY, C.J. and RUITENBERG, A.A. 1980. Geology of the Lake George antimony deposit, southern New Brunswick. Canadian Institute of Mining and Metallurgy Bulletin, **73**: 79–84.

PROCYSHYN, E.L. and MORRISSY, C.J. 1990. Geology of the Lake George Mine, southern New Brunswick. *In* Mineral Deposits of New Brunswick and Nova Scotia. *Edited by* D.R. Boyle. 8th IAGOD Symposium Field Trip Guidebook. Geological Survey of Canada, Open File 2157, pp. 58–67.

RUITENBERG, A.A. and FYFFE, L.R. 1982. Mineral deposits associated with granitoid intrusions and related subvolcanic stocks in New Brunswick and their relationship to Appalachian tectonic evolution. Canadian Institute of Mining and Metallurgy Bulletin, **75**: 83–97.

RUITENBERG, A.A., JOHNSON, S.C., and FYFFE, L.R. 1990. Epigenetic gold deposits and their tectonic setting in the New Brunswick Appalachians. Canadian Institute of Mining and Metallurgy Bulletin, **83**: 43–55.

SCRATCH, R.B., WATSON, G.P., KERRICH, R., and HUTCHINSON, R.W. 1984. Fracture-controlled antimony–quartz mineralization, Lake George deposit, New Brunswick: mineralogy, geochemistry, alteration, and hydrothermal regimes. Economic Geology, **79**: 1159–1186.

SEAL II, R.R., CLARK, A.H., and MORRISSY, C.J. 1987. Stockwork tungsten (scheelite)–molybdenum mineralization, Lake George, southwestern New Brunswick. Economic Geology, **82**: 1259–1282.

SEAL II, R.R., CLARK, A.H., and MORRISSY, C.J. 1988. Lake George, southwestern New Brunswick: a Silurian, multi-stage, polymetallic (Sb–W–Mo–Au–base-metal) hydrothermal centre. *In* Recent Advances in the Geology of Granite-Related Mineral Deposits. *Edited by* R.P. Taylor and D.F. Strong. Canadian Institute of Mining and Metallurgy, Special Volume 39, pp. 252–264.

THOMPSON, J.F.H. and NEWBERRY, R.J. 2000. Gold deposits related to reduced granitic intrusions. *In* Gold in 2000. *Edited by* S.G. Hagemann and P.E. Brown. Reviews in Economic Geology, **13**: 377–400.

THOMPSON, J.F.H., SILLITOE, R.H., BAKER, T., LANG, J.R., and MORTENSEN, J.K. 1999. Intrusion-related gold deposits associated with tungsten–tin provinces. Mineralium Deposita, **34**: 323–334.

THORNE, K.G. and LENTZ, D.R. 2001. Potential for gold deposits associated with evolved Sn–W–Mo granitic magmatism in southwestern and central New Brunswick. ORE Group Newsletter, **2**: 1, 4–7.

WATSON, G.P. 1981. Geology and geochemistry of the alteration zone surrounding the quartz–stibnite mineralization, Lake George antimony mine deposit, New Brunswick. Unpublished M.Sc. thesis, University of New Brunswick, Fredericton, New Brunswick, 208 p.

WHALEN, J.B. 1993. Geology, petrography, and geochemistry of Appalachian granites in New Brunswick and Gaspésie, Quebec. Geological Survey of Canada, Bulletin 436, 124 p.

YANG, X., LENTZ, D.R., and CHI, G. 2002a. Petrochemistry of Lake George granodioritic stock and related gold mineralization, York County, New Brunswick. Geological Survey of Canada, Current Research 2002-D7, pp. 1–10.

YANG, X., LENTZ, D.R., HALL, D.C., and CHI, G. 2002b. The petrology of the Lake George Granodiorite stock, New Brunswick: implications for crystallization conditions, volatile exsolution, and W–Mo–Au–Sb mineralization. Current Research 2002-E14, pp. 1–12.

Appendix. Sample Locations and Descriptions Used in this Study.

Sample	Location	Lithology	Alt.	Description
89-AR-081	SP1307,38N, E-wall	G	HB	altered granite in HW of vein sample 088, sent for dating
89-AR-082	SP1308, 74E, S-wall	S	HB	qtz-stib vn brecciated w pebby aspect, stib & native Sb
89-AR-083	SP1307,60N, W-wall	Gqmsg	GR	qmsg vn w greisen-like altn halo and host granite
89-AR-084	SP1307, 39N, W-wall	G	UG	'fresh' granitoid to compare w altered granite 081
89-AR-085	SP1308, 6N, E-wall	G	HB	several alt. gran pcs btw 'layers' of stib vns, compare w 086
89-AR-086	SP1308, 10N, W-wall	G	UG	less altered than 085
89-AR-087	SP1308, 6N, E-wall	G	HB	altered granitoid below HB vn 'layers' - to compare w 088
89-AR-088	SP1308, 13N, W-wall	G	UG	unalt granitoid - to compare w 087
89-AR-089	SP1307,40N, E-wall	G	HB	alt granitoid on HW stib vn - compare w 089
89-AR-090	SP1307, 37N, W-wall	G	UG	unalt granitoid - to compare w 089
89-AR-091	SP1307, 33N, E-wall	G	HB	alt granitoid on HW stib vn - compare w 092 - some vn impurities
89-AR-092	SP1307, 26N, E-wall	G	UG	unalt granitoid - to compare w 091
89-AR-093	SP1307, end of drift	G	UG	relatively fresh granite with phenocrysts
89-AR-094	SP1308, 18W, N-wall	GS	HB	granite/sediment contact
90-AR-095	SP1306, 95S, W-wall	LS	L	northern cont of lamprophyre w veining, small piece of adj sed
90-AR-096	SP1305, 50S, W-wall	Scalcsil		calc-silicate vns w zoned altn - buff, dk brown, brick red brown
90-AR-097	SP1305, 27S, E-wall	Scob4		vein w blue grey altn, yellow buff, then orange red brown
90-AR-098	SP1305, 32S, E-wall	q		white semi-transparent qtz vein w local abundant py - lens shaped vn
90-AR-099	SP1306,110S, W-wall	Svn		sediment & stib ll vein w dk altn - buff altn - brick red?
90-AR-100	Au, 28W, S-wall	qm		qtz vein w py - gray mineral is moly or stib
90-AR-101	Au, 56E, S-wall	qms		positive moly elsewhere in vein
90-AR-102	Au, 55E, N-wall	qms		semi-translucent qtz, moly?
90-AR-103	Au, N-drift, 15N	S	A	bedding in gold room
90-AR-104	Au, N-drift, W-wall	qms		semi-translucent qtz, coarse moly - locally abundant scheelite
90-AR-105	Au, N-drift end of drift	S	TG	Tiger-striped altn
90-AR-106	Au, 28W, N-wall	Lqm	A	qm vein in lamp. Separate - dk brn gray, buff & brick rd brown
90-AR-107	Au, 27W, N-wall	L	A	alt gray to dk gray, b-buff, c-brick red brown
90-AR-108	Au, 27W, N-wall	L	A	b-buff altn, c-brick red brown
90-AR-109	Au, 28W, N-wall	L	UIL	unalt lamp. dk red brown
90-AR-110	Au, 35W, N-wall	L	UIL	unalt lamp. dk red brown
90-AR-111	Au, 28W, N-wall	L	A	separate light gray, dk brown gray, buff and brick red brn
90-AR-112	Au, 29W, N-wall	L	UIL	unalt. lamp. dk red brown
90-AR-113	Au, 33W, N-wall	L	UIL	unalt. lamp. dk red brown
90-AR-114	Au, 46E, N-wall	S	A	separate light gray, dk brown gray & buff

Sample	Location	Lithology	Alt.	Description
90-AR-115	Au, 44E, N-wall	Sqm	A	qm vein disappeared in Au altn. Separate lt gy, dk gy-brn & buff
90-AR-116	Au, 46E, N-wall	S	UIS	unaltered sediment equiv of 114
90-AR-117	Au, 47E, N-wall	S	UIS	unaltered sediment equiv
90-AR-118	Au, drawpoint pile	S	A	separate light gray (sent for dating), dk gray & buff
90-AR-119	Au, 20E, floor	S	UIS	dark red brown unalt sediment
90-AR-120	Au, 32E, back	S	A	separate light gray, dk brown-gray & buff
90-AR-121	Au, 53E, S-wall	S	A	light gray gold alteration only
90-AR-122	Au, 20E, N-wall	S	A	separate - light gray, dk brown gray & buff
90-AR-123	Au, 17E, N-wall	S	UIS	unaltered sediment sent for dating
90-AR-124	Au, 21E, N-wall	S	A	gray, dk brown gray & buff
90-AR-125	Au, 24E, N-wall	S	UIS	unaltered sediment
90-AR-126	Au, 30E, N-wall	S	UIS	unaltered sediment
90-AR-127	SP264, 3W, N-wall	S	UIS	bedded fine sediment
90-AR-128	SP236, 35E, S-wall	S	UIS	roughly orient on So
90-AR-129	SP860, 3W, S-wall	S	?	bedded sediment w buff altn & red brn 'hematite' altn across porphyroblasts
90-AR-130	Au, 56W, S-wall	S	A	lighter creamy gray altn. within typical lt gray gold altn
90-AR-131	Au, 57W, S-wall	S	UIS	sample of sedimentary hornfels & smaller piece w porphyroblasts
90-AR-132	SP533, 15E, N-wall	S	UIS	on bedding surf
90-AR-133	SP512, 30W, S-wall	S	UIS	pin-striped altn
90-AR-134	SP858, 20W, S-wall	S	UIS	sample of bedded sediment w flutes
90-AR-135	SP875, 10W, S-wall	S	UIS	Sediment w refraction surf - look for bedding
90-AR-136	SP874, 8E, N-wall	S	UIS	look for bedding ll to orient surf
90-AR-137	SP872, 16W, S-wall	S	UIS	on So?, bed? Based on refraction across orient surf
90-AR-138	SP1025, 15W, N-wall	S	UIS	mm to 2 mm space parting surf - is this clvg?
90-AR-139	SP1027, 15W, N-wall	S	UIS	on So?, tiger stripes altn ll So, look for 2 clvgs
90-AR-140	SP861, 10 N, N-wall	S	UIS	dk red 'unalt'., 4.5 m into HW
90-AR-141	SP861, 20E, N-wall	S		brick red brown, 2 locations 1 m out from vein
90-AR-142	SP861, 27E, N-wall	S	HB	buff, 1 foot above HW
90-AR-143	SP861, 20E, N-wall	S	HB	dk brownish buff rind on vein
90-AR-144	SP873,35E, drawpoint	S	UIS	dk red brown, 7 m below FW
90-AR-145	SP873,35E, drawpoint	S		brick red brown, 2 m into FW 2 dm from buff altn
90-AR-146	SP873,35E, drawpoint	S	HB	buff altn, 1 dm into FW, second piece has dk gray rind on vein
90-AR-147	SP877, 15E, S-wall	Svn	A?HB	Au vein? Had dk gy buff, rd-brn altn - analyse for Au - gray min in vein
90-AR-148	SP877, 15E, S-wall	S	UIS	dk red brown, 5 feet into HW
90-AR-149	SP877, 15E, N-wall	S		brick red brown , 2 m into HW

Sample	Location	Lithology	Alt.	Description
90-AR-150	SP877, 7E, S-wall	S	HB	buff, on HW of vein
90-AR-151	SP888, 37S, W-wall	HB	HB	stib vein w altn halo to TG - has stib going to dk red brown color
90-AR-152	SP881, 17S, N-wall	L	UIL	least altered dk red brown, 1 foot into HW
90-AR-153	SP881, 17S, N-wall	L	UIL	least altered dk red brown, 4 feet into HW
90-AR-154	SP881, 17S, N-wall	L	UIL	least altered dk red brown, 9 feet into HW
90-AR-155	SP881,14E, S-wall	L	HB	buff just on HW of vein
90-AR-156	SP881, 15E, N-wall	L	HB	buff in HW of main vein
90-AR-157	SP881, 14E, S-wall	L	HB	buff
90-AR-158	SP881, 14E, N-wall	L		light red-brown, 1 foot into HW
90-AR-159	SP881, 15E, N-wall	L		light red-brown, 1 foot into HW
90-AR-160	SP881, 14E, N-wall	L		light red-brown, 1 foot into HW
90-AR-161	SP879,20E, drawpoint	S	HB	buff altn w dk gy stringers, break off dk rind on HW, age date
90-AR-162	SP879,20E, drawpoint	S		brick red brown altn (med), 3 feet into FW
90-AR-163	SP879,20E, drawpoint	S	UIS	least altered dk red brown, 6 m into FW
90-AR-164	SP881, 60W, N-wall	L	HB	buff altered just in FW
90-AR-165	SP881, 60 W, S-wall	L		red brown altn., 2 feet into FW
90-AR-166	SP881, 60 W, S-wall	L	UIL	unaltered dk red brown, less fresh than unaltered in Au room
90-AR-167	SP881, 60 W, S-wall	L	HB	buff altered on FW of vein, sent for age dating
90-AR-168	SP881, 60 W, S-wall	L		red brown, 4 feet into FW
90-AR-169	SP881, 60 W, S-wall	L	UIL	unaltered dk red brown, less fresh than unaltered in Au room
90-AR-170	SP1034, drawpoint	S	HB	buff, 1 dm into HW
90-AR-171	SP1034, drawpoint	S	Um	red brown, 4 feet into FW
90-AR-172	SP1034, drawpoint	S	UIS	unaltered, 2 m into FW
90-AR-173	SP1026,25W, drawpt	S	HB	buff, on HW of vein
90-AR-174	SP1026, 55W, raise	S	UIS	red brown but not distinctive from 175 - only use 175 in study
90-AR-175	SP1026, 25W, drawpt	S	UIS	half way btw red brown & dk red brown

NOTES:

? – uncertain rock type; || – parallel

A – gold-related alteration; calcsil – planar vein with calc-silicates; cob4 – carbonate, orange buff mineral± sulphides; E – east; FW – footwall; G – granodiorite; GR – greisen-like alteration; HB – Hibbard vein; HW – hanging wall; L – lamprophyre; LS – lamprophyre-sediment contact; LSqm – lamprophyre-sediment contact with quartz-molybdenite vein; N – north; q – quartz ± sulphides; QFP – quartz-feldspar porphyry; qm – quartz-molybdenite± sulphides; qms – quartz-molybdenite± sulphides; qmsg – quartz-molybdenite-green mineral± sulphides; S – south; S – metasedimentary rock (lithology column); So – bedding plane; SP – Survey Point (SP879(7E) = 7 feet east of SP); TG – tiger-striped alteration; UIS – unaltered sediment; UIG – unaltered granodiorite; UIL – unaltered lamprophyre; vn – vein; W – west

SURFICIAL GEOLOGY AND TILL GEOCHEMISTRY OF THE EASTERN TWO-THIRDS OF THE COLDSTREAM (NTS 21 J/06) MAP AREA, YORK AND CARLETON COUNTIES, NEW BRUNSWICK†

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The dominant glacial deposit in the eastern two-thirds of the Coldstream (NTS 21 J/06) map area is a blanket of basal till overlying bedrock. Glacial dispersal appears to be primarily by an early east-southeast-trending ice-flow event and a later south-southeast-trending event. The outstanding till geochemistry anomaly in the study area is associated with a cluster of sites in the vicinity of the Sisson Brook, Nashwaak and Manzer Brook mineral occurrences. Samples from three contiguous sites returned threshold anomalous to anomalous values for As, Bi, Cu, Mo, Pb, Sn, W and Zn, while samples from several adjacent sites returned similar values for some of these elements. A significant single site spot anomaly is present in the north-central part of the map area. As, Pb and Sb values at this site are comparable to the highest obtained in 12 years of till geochemistry investigations in west-central New Brunswick.

Le gîte glaciaire prédominant des deux tiers orientaux du secteur cartographique de Coldstream (SNRC 21 J/06) est une couverture de till de fond recouvrant le substrat rocheux. La dispersion glaciaire semble être principalement liée à un phénomène précoce d'écoulement glaciaire en direction est-sud-est et à un phénomène ultérieur en direction sud-sud-est. L'anomalie exceptionnelle de la géochimie du till dans le secteur d'étude est associée à un groupe d'emplacements à proximité des anomalies minérales du ruisseau Sisson, de Nashwaak et du ruisseau Manzer. Les échantillons de trois emplacements contigus ont présenté des valeurs anomales minimales à anomales d'As, de Bi, de Cu, de Mo, de Pb, de Sn, de W et de Zn, tandis que les échantillons de plusieurs emplacements adjacents ont présenté des valeurs analogues de certains de ces éléments. Une anomalie localisée marquée en un emplacement donné est présente dans le centre-nord du secteur cartographique. Les valeurs d'As, de Pb et de Sb de cet emplacement sont comparables aux valeurs les plus élevées obtenues en 12 ans d'étude de la géochimie du till dans le centre-ouest du Nouveau-Brunswick.

INTRODUCTION

Till geochemistry sampling was begun in the west half of the Coldstream (NTS 21 J/06) map area in 1998 and continued in 2000 and 2001. Sampling in the east half of the map area was begun in 2000 and completed in 2001. Sampling was conducted using the standard 2 km grid (1 sample / 4 km²) and the

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† New Brunswick Geological Surveys Branch ordinary budget.

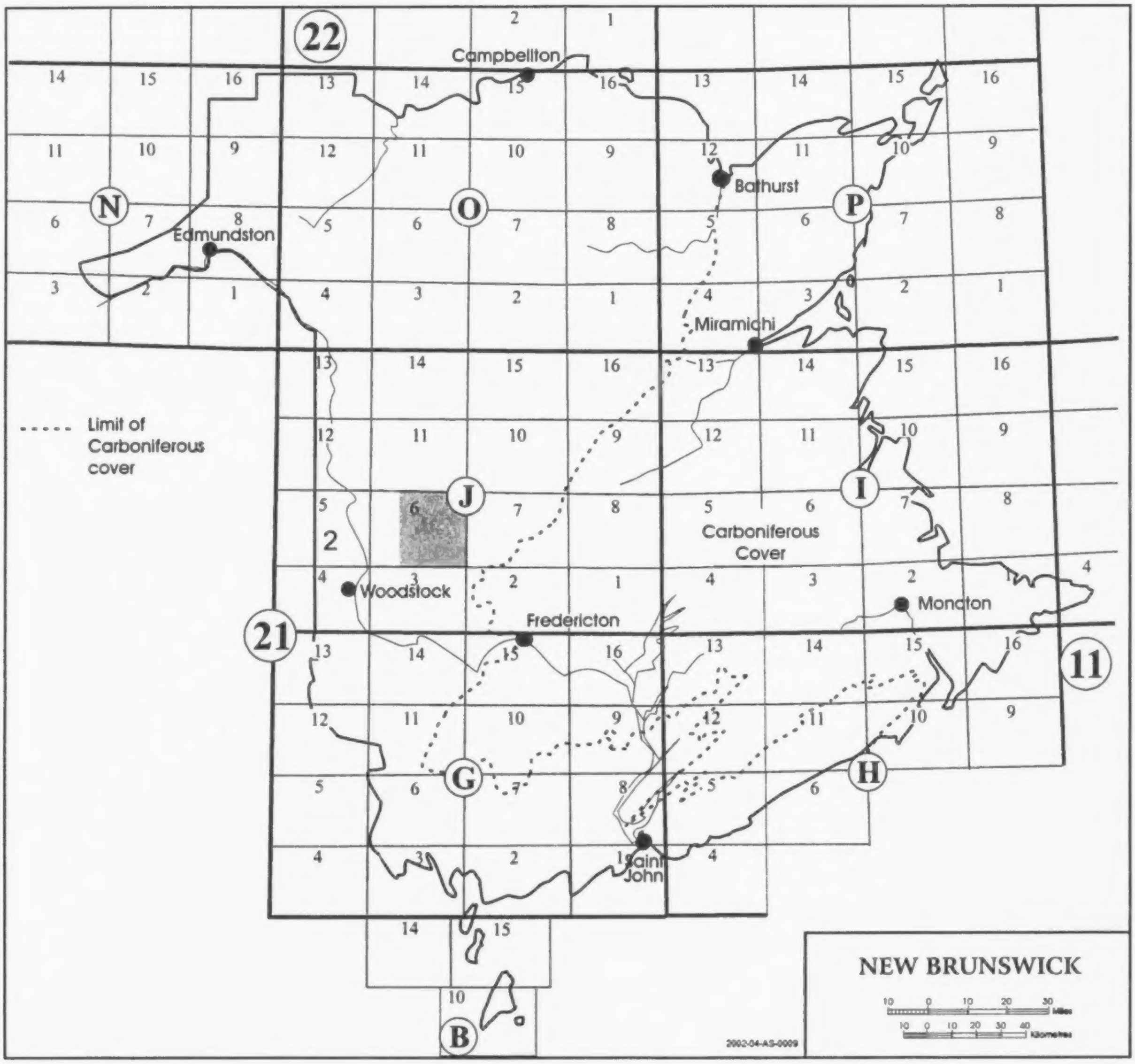

Figure 1. Location of the study area in the eastern two-thirds of the Coldstream (NTS 21 J/06W) map area.

same sampling procedures as used in earlier till geochemistry investigations in the adjacent Millville (NTS 21 J/03) map area (Seaman 1997, 1998, 1999a). For the purposes of this report the study area is the eastern two-thirds of the Coldstream map area (Figure 1), which encompasses all of the sites sampled in 2001, plus a number of sites that were sampled in 1998 or 2000. The sample sites are plotted on Figures 2, 3 and 4.

The available surficial geology and till geochemistry data for the sample sites in the study area are listed in detail in Seaman (2002). That report also includes the map co-ordinates for the sample sites, notes on access, description of the field and analytical methods, and comments regarding the reproducibility of

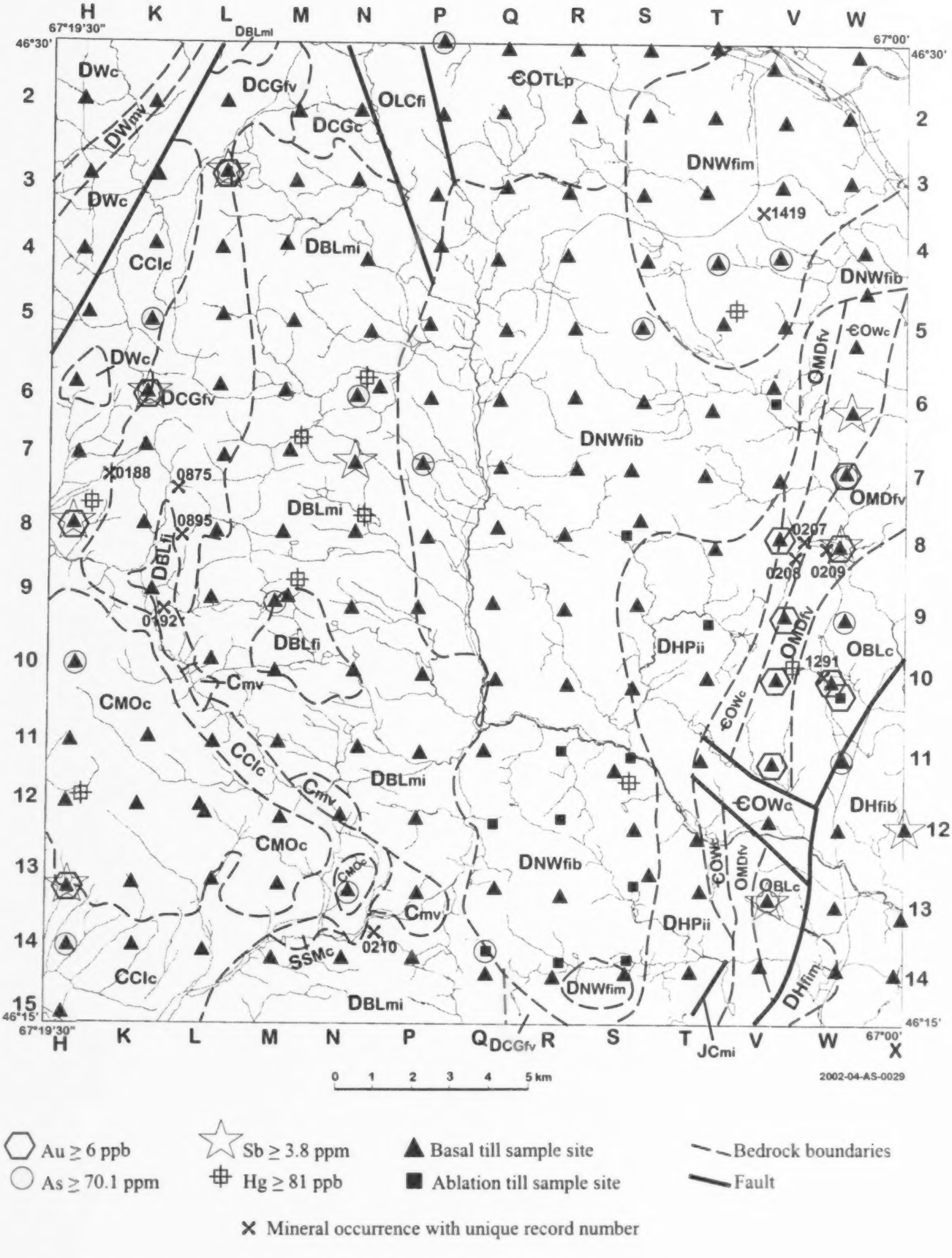

Figure 2. Bedrock geology, till sample site locations, and distribution of sites with elevated values for Au, As, Hg and Sb in the eastern two-thirds of the Coldstream map area.

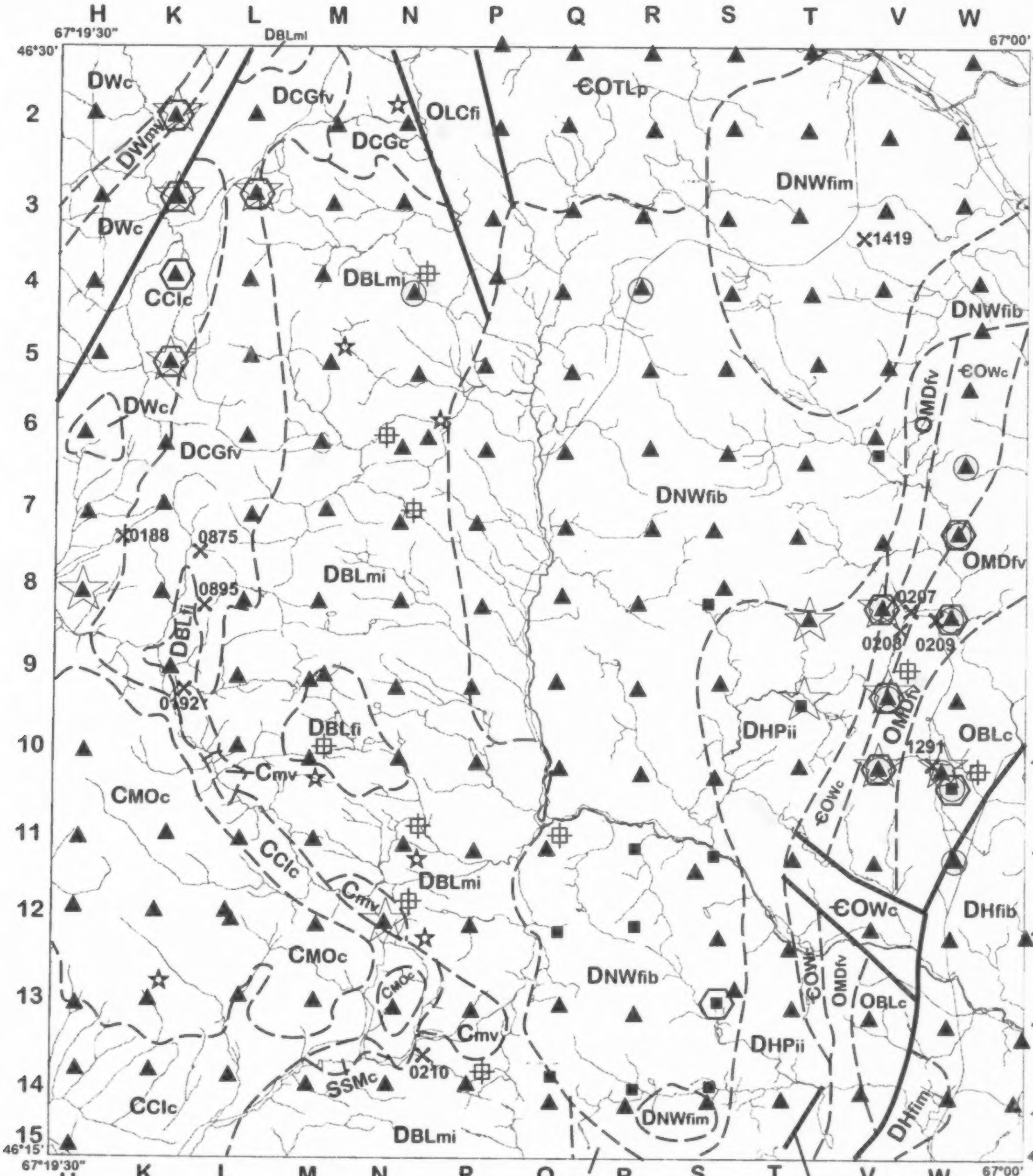

Figure 3. Bedrock geology, till sample site locations, and distribution of sites with elevated values for Cu, Pb, Zn, Co and Ni in the eastern two-thirds of the Coldstream map area.

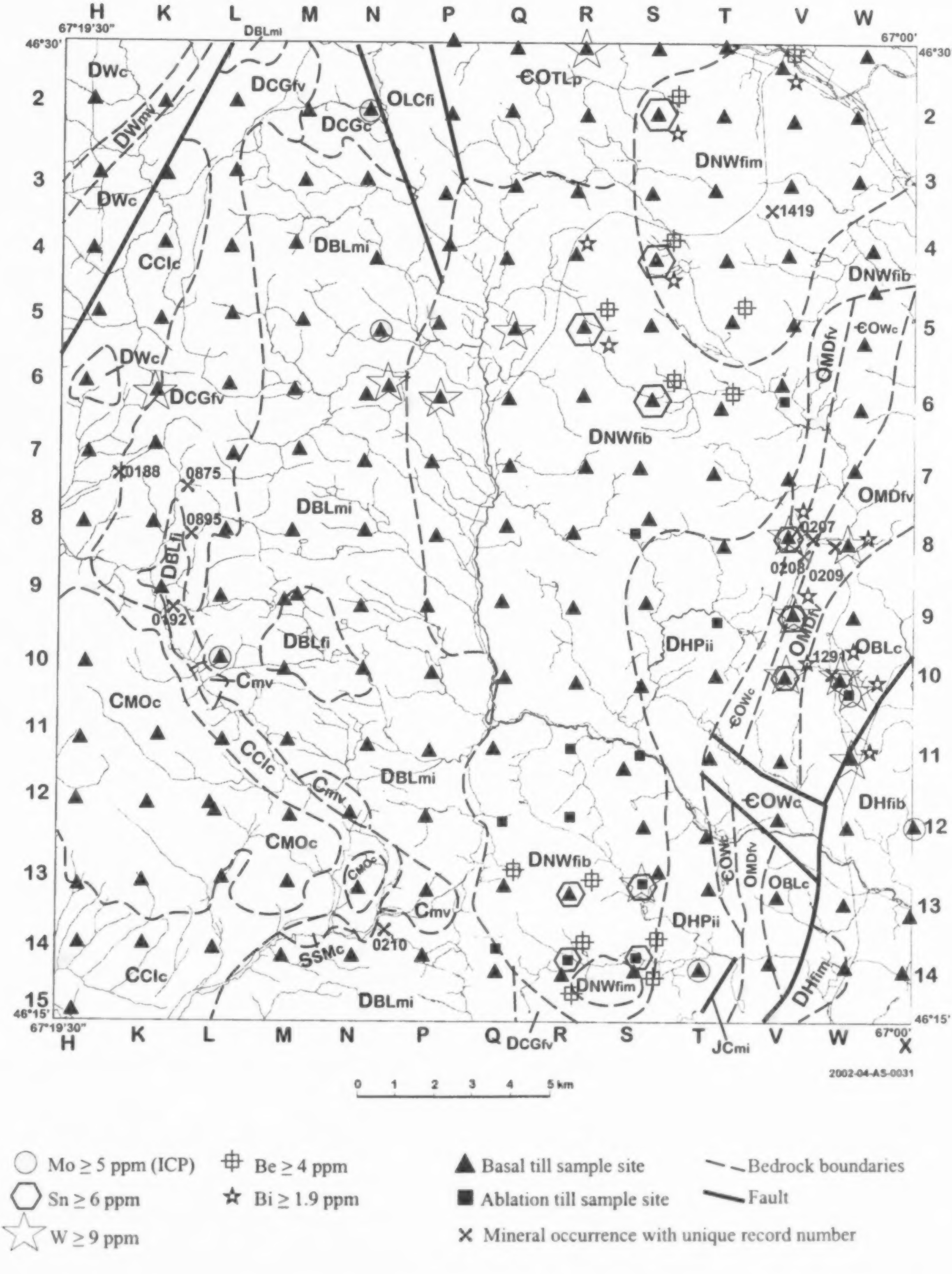

Figure 4. Bedrock geology, till sample site locations, and distribution of sites with elevated values for Mo, Sn, W, Be and Bi in the eastern two-thirds of the Coldstream map area.

analyses as indicated by the results obtained on analytical, field duplicate, and standard samples. The purpose of the current report is to discuss the results presented in the previous report (Seaman 2002).

BEDROCK GEOLOGY

The bedrock geology of the Coldstream map area was mapped at a scale of 1 inch equals 1 mile (1:63 360) by Anderson (1968). Detailed quarter-mile (1:15 840 scale) mapping was subsequently completed in the central part of the map area by St. Peter (1982), in the eastern part by Lutes (1981), and in the southern part by Venugopal (1982). Fyffe (1982) summarised this detailed work at 1:250 000 scale. A 1:50 000 scale compilation of the bedrock geology of the area was also prepared by Fyffe (1984). The bedrock geology of the central and eastern parts of the Coldstream map area is illustrated on Figures 2, 3 and 4. The bedrock unit descriptions (Table 1) are based on the above sources. The bedrock unit boundaries were derived from Fyffe (1982). The unit designations have been updated to 2001 standards (L.R. Fyffe, personal communication, 2002).

The Woodstock Fault system is a major northeast-trending fault that separates the Matapédia Cover Sequence to the northwest, from the Miramichi Terrane to the southeast (Fyffe and Fricker 1987). The Howard Brook Fault, easternmost of three major northeast–southwest-trending faults comprising the Woodstock Fault system in the Coldstream map area, passes through the northwest corner of the study area. The rocks to the northwest of the Howard Brook Fault in the study area belong to the Early Devonian Wapske Formation, and comprise slates and siltstones with interbedded sandstones and conglomerates and associated mafic volcanic rocks (St. Peter 1982). According to St. Peter (1982), this formation records a transition from marine conditions at the base to terrestrial conditions in the upper part.

To the east of the fault, the bedrock in the Coldstream map area can be divided into five roughly north–south-trending belts plus an outlier of Carboniferous clastic sedimentary rocks. The westernmost belt comprises the Early Devonian subaerial felsic volcanic rocks and associated shallow marine clastic sedimentary rocks of the Costigan Mountain Formation (St. Peter 1982). The next belt comprises the Early Devonian Becaguimec Lake Gabbro, which intrudes the eastern part of the Costigan Mountain Formation (St. Peter 1982). In turn, the gabbro was intruded by the Nashwaak Granite (Lutes 1981) to the east, which is also of Early Devonian age. Fyffe (1984) divides the Nashwaak Granite into two phases. The dominant phase is biotite granite. However, a muscovite–biotite phase outcrops in the northeastern corner of the study area and in a small area in the southern part of the study area. Lutes (1981) also included the granodioritic rocks along the southeastern edge of the granite as part of the Nashwaak Granite. These are now identified as the Howard Peak Granodiorite (New Brunswick Department of Natural Resources and Energy 2000). At the northern end of this granitic belt are a fault-bounded slice of the foliated Middle Ordovician Little Clearwater Brook Granite and an area underlain by the Cambro-Ordovician Trousers Lake Metamorphic Suite. The metamorphic suite consists of paragneiss, and was intruded by the Little Clearwater Brook Granite (Lutes 1981). To the east of the Nashwaak Granite and the Howard Peak Granodiorite is a southerly plunging anticline (Lutes 1981). The core of the anticline comprises Cambro-Ordovician clastic sedimentary rocks that are now interpreted as part of the Woodstock Group (New Brunswick Department of Natural Resources and Energy 2000). These are overlain by the Early Ordovician felsic volcanic rocks and associated slates of the Meductic Group, and by the clastic sedimentary rocks of the Late Ordovician Belle Lake Formation (also of the Meductic Group). The fifth belt of rocks comprises the biotite or muscovite–biotite phases of the Early Devonian Hawkshaw Granite (part of the Pokiok batholith; Lutes 1981, 1987). The Pokiok Batholith is mapped as being in fault contact with the older anticlinal rocks to the west.

Table 1. Table of Bedrock Formations, Central and Eastern Parts of the Coldstream Map Area (NTS 21 J/06)

System	Group	Formation	Map Unit	Lithology
Jurassic		Caraquet	JCmi	Grey, tholeiitic diabase dyke
Carboniferous	Pictou	Mountain View	CMOc	Grey sandstone and conglomerate
	Mabou	Carlisle	CClc	Red conglomerate and sandstone; minor red mudstone and breccia and grey arkose
		unnamed	Cmv	Grey, amygdaloidal mafic volcanic rocks
Devonian		Hawkshaw	DHfib	Pink, medium-grained biotite granite
			DHfim	Pink, medium-grained muscovite–biotite granite; minor garnet-bearing granite and pegmatite
		Nashwaak	DNWfib	Pink, medium-grained biotite granite
			DNWfim	Pink, medium-grained muscovite–biotite granite; minor garnet-bearing granite and pegmatite
		Howard Peak	DHPii	Grey, medium-grained, foliated biotite and hornblende—biotite granodiorite and tonalite
		Becaguimec Lake	DBLfi	Grey to pink, fine- to medium-grained, biotite and hornblende–biotite granite and granodiorite; minor reddish brown quartz–feldspar porphyry and red granophyre
			DBLmi	Green to grey, medium-grained diabase to gabbro; minor pinkish grey monzodiorite
	Tobique	Wapske	Dwmv	Green, amygdaloidal mafic volcanic rocks; minor sedimentary rocks
			Dwc	Grey slate and siltstone interbedded with sandstone and conglomerate
		Costigan Mountain	DCGfv	Pink feldspar porphyry, quartz–feldspar porphyry, and rhyolite tuff
			DCGc	Grey siltstone interbedded with sandstone and minor conglomerate
Silurian	Perham	Smyrna Mills	SSMc	Greyish brown to greyish blue, recrystalized limestone
Ordovician	Meductic	Belle Lake	OBLc	Grey lithic wacke, slate and minor calcareous siltstone
		Little Clearwater Brook	OLCfi	Pink, fine- to medium-grained, foliated granite
		McKiel Lake	OMKfi	Pink, medium-grained, foliated granite
	Meductic		OMDfv	Buff to grey rhyolite and crystal tuff interbedded with grey to black slate
Cambrian–Ordovician	Woodstock		€Owc	Olive-green to grey wacke interbedded with grey–green and maroon slate
	Trousers Lake		€OTLp	Interlayered grey cordierite-bearing quartzofeldspathic paragneiss and sillimanite-bearing schist, grading to medium-grained granitoid

In the western part of the study area, adjacent to the Howard Brook Fault, an outlier of Carboniferous rocks overlies the Costigan Mountain Formation and the Becaguimec Lake Gabbro. The outlier comprises the red clastic sedimentary rocks of the Early Carboniferous Carlisle Formation, which in the southern part of the area are associated with an unnamed mafic volcanic unit, and the overlying coarse clastic sedimentary rocks of the Late Carboniferous Mountain View Formation.

Several mineral occurrences have been reported from the study area (Merlini 1999). The MacIntosh Brook (URN 0192), Pokiok Brook North (URN 0875) and Pokiok Brook South (URN 0895) Cu occurrences are associated with the Costigan Mountain Formation or small felsic intrusions within the formation. The Becaguimec Lake (URN 0210) Cu–Ni occurrence lies within the gabbro of the same name. The Sisson Brook (URN 0207 and 0208), Nashwaak (URN 0209) and Manzer Brook (URN 1281) multi-element occurrences lie within the anticline exposing the Meductic and Woodstock groups. A new multi-element mineral occurrence was found in the Nashwaak Granite during the course of the till sampling program. Identified as the Deersdale occurrence, it has been assigned URN 1419 (Seaman 2002). The host rock is felsic porphyry (L.R. Fyffe, personal communication, 2002). In addition, the Early Carboniferous Carlisle Formation has been identified as the source of anomalous As, Au and Sb, and probably Sn and W, in the overlying till (Seaman 2001b).

SURFICIAL GEOLOGY

Previous studies

Detailed (1:50 000 scale) surficial geology mapping of the Coldstream map area has not been conducted. However, Rampton and Paradis (1981) conducted reconnaissance mapping (1:250 000 scale) in the area, and Hunter and Lavergne (1982) mapped the surficial granular aggregate deposits at 1:50 000 scale. The results of these studies and earlier miscellaneous observations are summarized by Rampton *et al.* (1984).

Rampton and Paradis (1981) mapped the study area as predominantly veneered by till (morainal veneer, generally discontinuous and less than 0.5 m thick over bedrock). In addition, several areas blanketed by thicker till (morainal blanket, generally 0.5 to 1.5 m thick overlying bedrock) were identified, as were a number of areas of essentially bare bedrock (Rampton and Paradis 1981). Also mapped by Rampton and Paradis (1981) were: a discontinuous belt of ablation moraine in the southeastern and east-central parts of the study area; an area blanketed by 0.5 to 1.5 m of lacustrine material in the northeastern corner of the area; glaciofluvial plains associated with the above lacustrine unit (lying to the southwest of it) and with the Nashwaak River valley; and an extensive alluvial plain associated with the Southwest Miramichi River valley. There are considerable discrepancies between the glaciofluvial deposits identified by Rampton and Paradis (1981) and those mapped by Hunter and Lavergne (1982). Hunter and Lavergne (1982) did not recognize the glaciofluvial unit associated with the lacustrine unit of Rampton and Paradis (1981), but did identify a glaciofluvial unit within the area mapped as lacustrine and alluvial by Rampton and Paradis (1981). Hunter and Lavergne (1982) also map the glaciofluvial deposits along the upper reaches of the Nashwaak River as significantly less extensive than mapped by Rampton and Paradis (1981). Hunter and Lavergne (1982) also indicate that the glaciofluvial deposits are largely continuous down the Nashwaak River valley rather than being interrupted by the belt of ablation moraine.

Snow and Coker (1987) present a sketch map of glacial landforms in an area of approximately 80 km^2 in the vicinity of the Sisson Brook and Nashwaak mineral occurrences. They identified five map units: thin ground moraine over bedrock; ground moraine; fluted ground moraine; ribbed moraine; and hummocky disintegration moraine. Ice flow directions toward the south-southeast (160 ± 10°) and toward the southeast (130 ± 10°) were determined (Snow and Coker 1987), based on the orientations of fluted ground moraine and ribbed moraine, and on till fabric trends.

Observations arising from the current study

Basal till: Lamothe (1992) has suggested that bedrock in the Miramichi Highlands is generally overlain by a thin till sheet generally less than 3 m in thickness, i.e., a morainal blanket, as defined by Rampton and Paradis (1981). The observations made during the current study indicate that this would be a reasonable assessment of till thickness for the eastern two-thirds of the Coldstream map area. Bedrock or possible bedrock (i.e., possibly a large boulder) was encountered at the base of the till section at only eight of the 167 basal till sample sites, all at depths of 0.5 m or more. Average test pit depth in basal till was 84 cm, varying from 56 to 130 cm. Till thickness exceeded 0.7 m at all three sites (CS-N06a, -N10 and -P14) that were excavated in areas mapped by Rampton and Paradis (1981) as rock, and bedrock was not encountered at the base at these sites.

Our observations indicate that the basal till in the study area is generally moderately compact to very compact. Colour varies from olive brown through to reddish brown. As reported by Seaman (2000) the reddish brown material from the Carlisle Formation was dispersed toward the east-southeast during an early phase of glaciation and subsequently toward the south-southeast. Hence, brown to reddish brown colours predominate in the area overlying or to the east and southeast of the Carlisle Formation. Elsewhere the colours are predominantly olive brown to yellowish brown. The basal till in the study area exhibits a highly variable texture as a consequence of the variety of bedrock units present. Using the definitions of Folk (1968), basal till texture ranges from slightly gravelly mud to silty sandy gravel. In the western part of the study area the texture is most variable. In the eastern part of the area, underlain primarily by granitic rocks, the basal till tends to be sandier (i.e., gravelly muddy sand to silty sandy gravel). The basal till overlying both the granites and the Carlisle Formation also tends to be somewhat less gravelly (i.e., predominantly <50 %) than that elsewhere in the study area.

Ablation till: In general, the ablation moraine units identified by Rampton and Paradis (1981) are less extensive than mapped. Basal till extending to the surface was encountered at a dozen sample sites lying within the mapped limits of ablation moraine. However, in the area to the south of the Nashwaak River the ablation moraine is more extensive than mapped by Rampton and Paradis (1981). Between sites CS-R11 and -R12 ablation till exceeding 1 m in thickness was encountered at a number of sites, including one on the crest of the hill with a spot height of 385 m on the topographic map. No basal till was observed within a kilometre of these two sites nor site CS-Q12.

Our observations indicate that the ablation till in the study area varies from very loose to moderately compact (locally cemented) gravelly silty sand to gravel. Its colour is yellowish brown to olive, except in the extreme southern part of the study area where the incorporation of material derived from the Carlisle Formation results in a brown colour.

Glaciofluvial deposits: Insufficient data was collected during the current study to fully assess the distribution of glaciofluvial deposits. However, the following comments can be made:

1. There is definitely glaciofluvial material in the Half Moon Pit area in the northeastern corner of the study area, as identified by Hunter and Lavergne (1982). Similar material was also observed in the area to the north of the Southwest Miramichi River at Deersdale;
2. There is definitely glaciofluvial material in the southern part of the area of glaciofluvial deposits mapped by Rampton and Paradis (1981) to the south of the supposed lacustrine unit. The sample site for grid point CS-W04 had to be moved approximately 500 m to the northeast of the grid point because of the presence of glaciofluvial sand and gravel near the grid point. Even then, the upper 0.5 m of material at the sample site was of glaciofluvial origin (overlying basal till). However, whether the extent of this glaciofluvial unit is as great as mapped by Rampton and Paradis (1981) has not been determined;
3. The glaciofluvial unit in the upper part of the Nashwaak River valley is somewhat less extensive than mapped by Rampton and Paradis (1981), as indicated by the presence of basal till at sites CS-Q06 and -Q07. However, whether the extent is as limited as indicated by Hunter and Lavergne (1982) has not been determined;
4. The glaciofluvial deposits in the Nashwaak River valley are continuous through the area of ablation moraine mapped by Rampton and Paradis (1981), as indicated by Hunter and Lavergne (1982); and
5. In the extreme southeastern corner of the study area, the glaciofluvial deposits along the Nashwaak River valley are somewhat more extensive than mapped by either Hunter and Lavergne (1982) or Rampton and Paradis (1981).

Glaciolacustrine or lacustrine deposits: No evidence was found of the lacustrine blanket mapped by Rampton and Paradis (1981) in the northeastern corner of the study area. At all three sample sites within its mapped area (CS-W01, -W02 and -W03) the soil parent material comprises basal till. The only probable glaciolacustrine material observed in the study area was at site CS-K09. At this site, in the valley of the North Branch Becaguimec Stream, approximately 0.3 m of probable glaciolacustrine muddy sand to sandy mud underlies 0.4 m of colluvium and overlies approximately 0.2 m of glaciofluvial gravelly sand (which in turn overlies basal till).

Glacial erosion trends: No glacial striae have been observed in the study area, either during the present study or during previous investigations (cf., Rampton and Paradis 1981). Examination of the aerial photographs for the area suggests that probable glacially streamlined bedrock landforms have orientations that lie in the 90° sector between east-northeastward to south-southeastward. Orientations toward the east-southeast are particularly prevalent in the south-central part of the study area. This is the area where Seaman (2000) identified an early east-southeast-trending dispersal train.

TILL GEOCHEMISTRY

Previous studies

Reconnaissance investigations: A reconnaissance geochemical survey of glacial deposits in west-central New Brunswick was conducted in 1983 by the Geological Survey of Canada (GSC) (Kettles and Wyatt 1986), which included three sample sites in the westernmost part of the study area. Subsequently, the GSC carried out a more extensive, multi-year (1985 to 1988), regional till geochemistry survey in the southern Miramichi Zone (Lamothe 1990, 1992). A further 109 sites were sampled in the study area, 12 sites in 1985, 8 sites in 1986, 76 sites in 1987 and 13 sites in 1988 (Lamothe 1990). In addition, the samples collected in 1983 were reanalyzed. Because the analyses were carried out over several years, the number of elements reported for each sample varied. Values for As, Co, Cr, Cu, Fe, Mn, Ni and Zn obtained from clay faction separates, and for As, Au and Sb obtained from silt-plus-clay fraction separates, were reported for all samples. Values for Ag, F, Hg, Mo, Na Pb, Sn, U and W were obtained for some of the clay fraction separates, and values for Co, Cr, Fe, Hg, Mo, Ni, Th, U and W for some of the silt-plus-clay fraction separates.

Kettles and Wyatt (1986) indicate that till was sampled at their three sites. Unfortunately, Lamothe (1990) does not indicate the nature of the sampled material in the second GSC project. However, six of the sample sites (GSC sites 87LFA0125, 87LFA0130, 87LFA0138, 87LFA0144, 87LFA0145 and 87LFA0146) lie within the limits of glaciofluvial deposits mapped by Hunter and Lavergne (1982). Another three sites (85LFA0135, 85LFA0136 and 87LFA8052) lie within the area of glaciofluvial deposits mapped by Rampton and Paradis (1981) in the upper Nashwaak River valley, and site 87LFA8063 lies in an area of glaciofluvial material observed during the course of the current study. A further 15 sites (85LFA0017, 85LFA0024, 87LFA0128, 87LFA0129, 87LFA0133 to 87LFA0137, 87LFA143, 87LFA0147, 87LFA8150, 87LFA8151, 88LFA0129 and 88LFA0130) lie within areas mapped as ablation moraine by Rampton and Paradis (1981) and, thus, may have been collected from ablation till. In addition, several sites were sampled within 1 km of another site. With the above sites removed from consideration, the effective average basal till sample density for the study area based on the GSC projects is about one sample per 9 km^2. However, the samples in these two surveys were collected primarily along roads and, thus, the coverage of the area is irregular. Sample sites are particularly sparse in the part of the southern half of the current study area that lies to the west of the Sisson Brook mineral occurrences.

Lamothe (1990) presented proportional dot plots for As, Cu, Hg, Pb, Sn, U, W and Zn in the clay fraction and As, Sb and Au in the clay-plus-silt fraction for the southern Miramichi Zone. In his final report Lamothe (1992) interpreted the geochemical data presented in the earlier report (Lamothe 1990), and presented colour element distribution maps for Cu, Pb, Zn, Sn, W, U, Sb and Hg for the entire Miramichi Zone. Dispersal trains for Cu, Pb, W and Zn extend south-southeastward from the area of the Sisson Brook mineral occurrences (at the 95th percentile level for Cu and W, and at the 75th percentile level for Pb and Zn) for distances of 10 to 15 km (Lamothe 1992). An area of W with values exceeding the 95th percentile level [described by Lamothe (1992) as a flame-shaped anomaly] is present in the north-central part of the current study area. Finally, Lamothe (1992) identified a north-south belt of elevated U values (greater than the 75th percentile level) associated with the granites in the eastern part of the study area.

Also included in Lamothe's (1992) report is a map indicating the locations of sites at which Au values were greater than 10 ppb. Three such sites were identified in the current study area, two in the northern part of the area and one to the south-southeast of the Sisson Brook mineral occurrences.

In addition to the reconnaissance till geochemistry investigation, a regional stream-sediment geochemistry survey has been completed recently for the Coldstream map area (Friske *et al.* 2002). While the results of the two types of survey are expected to be significantly different as a consequence of their markedly different sample populations, they can serve to complement one another.

The west half of the Coldstream map area: The results of sampling in the west half of the Coldstream map area were reported by Seaman (2001a). Two observations of significance to the current study arise from the earlier investigation. First, a strong association was noted between the areas underlain by the red clastic sedimentary rocks of the Early Carboniferous Carlisle Formation and the distribution of elevated values for As, Sb, Sn and W, and to a lesser extent Au. This association was attributed to mineralization within the Carlisle Formation (Seaman 2001b). Second, a belt of elevated As, Pb and Zn values was identified in the area of the South Branch Southwest Miramichi River. This belt was interpreted as a probable dispersal train extending from known mineral occurrences in the Juniper (NTS 21 J/11) map area to the north (Seaman 2001b).

The Sisson Brook area: The area around the Sisson Brook mineral occurrences was studied in detail by Snow and Coker (1987). Most of their samples were collected from backhoe trenches. As noted above, they identified two ice-flow directions, southeastward (approx. 130°) and south-southeastward (approx. 160°). Both short and long distance glacial transport were recognized. Up-ice from Nashwaak Ridge, they noted a rapid change in the dominant pebble lithology of the till upon crossing bedrock contacts. Geochemical dispersal trains from known mineralized zones were only 300–400 m long. This short dispersal distance was ascribed to shearing of basal debris up into the body of the ice as a consequence of compressive flow resulting from the butting of the ice sheet against the nearby Nashwaak Ridge. However, this effect also engendered long distance transport, as material sheared up into the ice sheet was carried over Nashwaak Ridge and deposited approximately 8 km to the south-southeast with no apparent interconnecting dispersal train (Snow and Coker 1987). Whole till samples (<2 mm, ground to <75 μm) were found to clearly delineate zones of Cu, Mo and W mineralization.

The northern part of the adjacent Millville map area: A number of geochemical anomalies were identified at sites in the northern sample rows of the adjacent Millville (NTS 21 J/03) map area (Seaman 1997, 1998). [Note: the column lettering for the Millville map area corresponds to that for the Coldstream map area, so that site CS-P14, for example, is 2 km north of site MV-P01]. A dispersal train of As and Sb with Sn and W was identified by Seaman (1998) immediately to the south of the western part of the current study area (column H). The source of this dispersal train has since been identified as the Carlisle Formation red clastic sedimentary rocks in the vicinity of Cloverdale (Seaman 2001b). Seaman (1999b) discussed the results of follow-up sampling in the vicinity of several of the other anomalies. Anomalous Pb at site MV-L01a, Pb and Zn at site MV-N03a, and Cu and Mo with elevated As and Pb as site MV-X02a were suggested to be derived from local bedrock sources. However, the elevated Cu, Mo, Sn and Zn values at site MV-S01a were suggested to be related to a bedrock occurrence farther to the north, in the Coldstream map area (Seaman 1999b).

Determination of elevated values

In previous 1:50 000 scale till geochemistry studies in west-central New Brunswick, elevated values have been defined as including both anomalous and threshold anomalous values. Anomalous values were defined as those equal to or greater than four standard deviations above the mean value determined for the basal till data obtained for the study area and subjected to a one-step trimming process to remove extremely high values (e.g., Seaman 1997, 1998). Non-detectable values were arbitrarily assigned a value equal to half of the detection limit for calculation purposes. Threshold anomalous values were defined as those equal to or greater than two standard deviations above the mean but less than the anomalous values. The same procedures were used to determine threshold anomalous and anomalous levels for the purposes of this report. The means and standard deviations calculated for each element are summarized in Table 2. The number of outliers (i.e., the number of values excluded from the calculation process as a result of the one-step trim) are also indicated, as are the calculated threshold values and the minimum anomalous values (at the same level of precision as the values reported by the laboratory).

Even though the calculated means and standard deviations pertain specifically to basal tills, the same values are used for the ablation till samples, since there are insufficient ablation till samples to calculate statistically valid mean and standard deviation values. As has been shown in previous studies (e.g., Seaman 1992), the values obtained for non-lithophile elements tend to be comparable between ablation till and basal till in the same area. However, because of the different transport mechanism experienced by the ablation till it will not necessarily indicate the same direction of dispersal as will the basal till.

Distribution of sites with elevated values

Distribution of threshold anomalous to anomalous sites: The distribution of sites with elevated values of Au, As, Sb and Hg are indicated on Figure 2. Figure 3 illustrates the distribution of sites with elevated values for Cu, Pb, Zn, Co and Ni, while Figure 4 illustrates the distribution of sites with elevated values for Mo, Sn, W, Be and Bi. Au and the five elements on Figure 4 are affected by the nugget effect. Therefore, for sites for which duplicate analyses were obtained, an elevated value is indicated even if one of the duplicate analyses returned less than elevated values and the average value was less than the calculated threshold value.

The Sisson Brook area: The area in the vicinity of the Sisson Brook (URNs 0207 and 0208), Nashwaak (URN 0209) and Manzer Brook (URN 1281) mineral occurrences, in the east-central part of the study area, stands out clearly on Figures 2, 3 and 4. The samples from sites CS-V08, -V09 and -V10 returned elevated values for As, Bi, Cu, Mo (by ICP), Pb, Sn, W and Zn (Table 3), and samples from several adjacent sites returned elevated values for some of these eight elements.

Snow and Coker (1987) noted that there was no apparent long-distance dispersal train extending from the Sisson Brook mineral occurrences, due to the effect of the presence of Nashwaak Ridge. This seems to be confirmed by the generally low geochemical values obtained for the sample from site CS-W09 (Table 3), which lies to the south-southeast of the Sisson Brook occurrences. However, as noted above, Lamothe's (1992) figures indicate dispersal trains trending south-southeastward from the Sisson Brook area for distances in the order of 10 to 15 km. Several of the proportional dot plots presented in Appendix 3 of Seaman (2002) also suggest dispersal over several kilometres toward the south to south-southeast at the sub-threshold level. There are three possible explanations for this apparent contradiction. First, the mineralized bedrock could lie in a north-northeast-trending belt extending along the structural trend from the vicinity of site CS-V10 to the vicinity of site CS-W06. Site CS-V10 is just to the east of the crest of Nashwaak Ridge. Therefore, debris from a bedrock source in this vicinity could be transported downslope by the regional south-southeastward ice flow without being thrust up out of the basal zone, permitting the formation of the dispersal trains identified by Lamothe (1992) and Seaman (2002). The second alternative is that the Nashwaak Ridge served to deflect some of the basal ice-flow in the Sisson Brook area toward the south, with the basal ice climbing diagonally up the slope of the ridge until it overtopped the ridge in the vicinity of site CS-V10. From this point the basal ice would be free to follow the regional ice flow trend, resulting in a dogleg dispersal train with southward- and south-southeastward-trending segments. The third alternative is a combination of the first two. The topography to the north of Sisson Brook is not conducive to explaining the elevated values obtained for sites CS-W06 and -W07 as resulting from north-northeastward diversion of basal ice-flow. The elevated values at these sites more likely represent mineralization in bedrock in the vicinity of the site. Therefore, it is possible that a belt of mineralized bedrock extends from the Sisson Brook occurrences toward the north-northeast, accounting for the elevated values in this area, while the elevated values to the south reflect dispersal from the known

Table 2. Threshold and Anomalous Geochemical Levels for Basal Till, Central and Eastern Parts of the Coldstream Map Area (NTS 21 J/06)

Element		Analytical Method	Mean *	Standard Deviation *	Outliers	Threshold Value *	Anomalous Value (≥) *
Ag	Silver	ICP	0.70	0.35	0	1.4	2.2
Al	Aluminum	ICP	6.015 %	2.561 %	0	11.14 %	16.26 %
As	Arsenic	INAA	24.13	22.98	3	70.1	116.1
Au	Gold	INAA	2.0 ppb	1.9 ppb	1	6 ppb	10 ppb
Ba	Barium	INAA	384	105	1	600	810
Be	Beryllium	ICP	1.7	1.2	2	4	7
Bi	Bismuth	ICP-MS	0.65	0.59	4	1.9	3.1
Br	Bromine	INAA	10.28	8.89	3	28.1	45.9
Ca	Calcium	ICP	0.519 %	0.429 %	1	1.38 %	2.24 %
Cd	Cadmium	ICP	<0.3	-	2	-	0.3
Ce	Cerium	INAA	100.0	29.1	0	159	217
Co	Cobalt	INAA	16.7	5.8	1	29	40
Cr	Chromium	INAA	87.3	26.2	0	140	192
Cs	Cesium	INAA	10.0	5.9	3	22	34
Cu	Copper	ICP	24.2	12.7	2	50	76
Eu	Europium	INAA	1.47	0.32	0	2.1	2.8
Fe	Iron	INAA	4.085 %	0.852 %	1	5.79 %	7.50 %
Ge	Germanium	ICP-MS	0.58	0.23	0	1.1	1.6
Hf	Hafnium	INAA	10.7	2.9	0	17	23
Hg	Mercury	CV-AAS	34.8 ppb	22.9 ppb	2	81 ppb	127 ppb
K	Potassium	ICP	1.701%	0.554 %	0	2.81 %	3.92 %
La	Lanthanum	INAA	46.62	12.97	1	72.6	98.5
Lu	Lutetium	INAA	0.665	0.191	3	1.05	1.43
Mg	Magnesium	ICP	0.948 %	0.398 %	0	1.75 %	2.54 %
Mn	Manganese	ICP	674.7	269.1	1	1213	1751
Mo	Molybdenum	ICP	1.8	1.2	2	5	7
Mo	Molybdenum	INAA	2.8	3.0	1	9	15
Na	Sodium	INAA	1.231%	0.492 %	0	2.22 %	3.20 %
Nd	Neodymium	INAA	35.4	11.1	0	58	80
Ni	Nickel	ICP	40.8	15.2	1	72	102
Ni	Nickel	INAA	27.7	26.3	1	81	133
P	Phosphorus	ICP	0.0659 %	0.0371%	1	0.141 %	0.215 %
Pb	Lead	ICP	28.7	15.7	2	61	92
Rb	Rubidium	INAA	105.1	44.4	1	194	283
S	Sulphur	ICP	0.0104 %	0.0065 %	3	0.024 %	0.037 %
Sb	Antimony	INAA	1.43	1.14	1	3.8	6.0
Sc	Scandium	INAA	14.26	3.23	1	20.8	27.2
Se	Selenium	ICP-MS	0.61	0.25	2	1.2	1.7
Sm	Samarium	INAA	7.98	2.69	1	13.4	18.8
Sn	Tin	ICP-MS	2.2	1.5	0	6	9
Sr	Strontium	ICP	72.5	28.2	0	129	186
Ta	Tantalum	INAA	1.37	1.00	0	3.4	5.4
Tb	Terbium	INAA	0.90	0.60	1	2.2	3.4
Te	Tellurium	ICP-MS	<0.1	-	2	-	0.1
Th	Thorium	INAA	16.25	7.81	0	31.9	47.5
Ti	Titanium	ICP	0.583 %	0.150 %	1	0.89 %	1.19 %
Tl	Thallium	ICP-MS	0.69	0.28	2	1.3	1.9
U	Uranium	INAA	4.35	2.38	2	9.2	13.9
V	Vanadium	ICP	94.6	27.9	1	151	207
W	Tungsten	INAA	1.8	3.6	2	9	17
Y	Yttrium	ICP	23.3	12.1	1	48	72
Yb	Ytterbium	INAA	4.18	1.25	3	6.7	9.2
Zn	Zinc	ICP	74.0	21.2	2	117	159
Zn	Zinc	INAA	85.0	42.7	0	171	256

Note: * values are parts per million (ppm) unless indicated otherwise.

Table 3. Values for As, Bi, Cu, Mo (by ICP), Pb, Sn, W and Zn for Sites in the Vicinity of the Sisson Brook, Nashwaak and Manzer Brook Mineral Occurrences

Site	As	Bi	Cu	Mo	Pb	Sn	W	Zn
CS-V08-1 (aT)	[26.1]	[1.8]	[28]	(1)	(24)	[3]	11	(61)
CS-V08-2	108	**5.7**	**91**	5	81	7	(<1)	**174**
CS-V08-2 dupl.	113	**6.8**	**85**	[4]	80	6	(<1)	**178**
CS-V09	**159**	**7.0**	**117**	**19**	63	6	**81**	154
CS-V10	**141**	**3.2**	55	**13**	**140**	6	**19**	146
CS-V11-1 (aT)	77.0	(0.6)	[28]	[3]	[39]	(2)	(<1)	(67)
CS-V11-2	83.8	[0.8]	[36]	[3]	[37]	(2)	(<1)	[82]
CS-W06	[45.4]	(0.5)	73	(1)	[37]	(2)	(<1)	[84]
CS-W07	91.2	(0.6)	67	[2]	**124**	[3]	(<1)	[112]
CS-W08	**134**	**9.0**	**76**	[4]	71	[4]	**31**	[114]
CS-W09	[26.8]	(0.6)	[29]	(1)	(24)	(1)	(<1)	[81]
CS-W10a (aT)	**121**	**3.5**	**81**	5	62	[4]	**17**	[105]
CS-W10b	98.4	**8.7**	**110**	5	[60]	[5]	**36**	117
CS-W11	[69.1]	2.9	50	[2]	[37]	[4]	10	[110]

Notes: Samples are from basal till, unless otherwise noted (aT – ablation till)
(10) less than average value
[20] average to above average value
30 threshold anomalous value
40 anomalous value

mineral occurrences. Further investigation, both surficial and bedrock, will be required to determine the most likely of these scenarios.

The elevated values at sites CS-W08, -W10a and -W10b on the eastern flank of Nashwaak Ridge are easier to explain. Site CS-W08 lies close to the Nashwaak (URN 0209) mineral occurrence, and the elevated values obtained for the sample from this site could reflect that source. They could also reflect glacial dispersal eastward from the northernmost Sisson Brook occurrence around the head of Nashwaak Ridge along the trend of the brook. Sites CS-W10a and -W10b lie just down-ice of the Manzer Brook (URN 1281) mineral occurrence, and the elevated values obtained for the samples from these sites most likely reflect the contribution of material from that source. Whether dispersal trains will be identified extending from these two mineral occurrences awaits sampling in the adjacent Napadogan (NTS 21 J/07) map area.

Correspondence with anomalies in the northern part of the Millville map area: There are no Pb, Pb–Zn or Cu–Mo anomalies in the southern part of the Coldstream map area that would correspond to the anomalies identified in the northern part of the Millville map area. Therefore, the interpretation that the anomalies in the latter area represent local sources (Seaman 1999b) is most likely correct. Neither can the elevated values for Cu and Zn at site MV-S01a be related to a source to the north. However, threshold anomalous values for Sn were obtained for the basal till sample from site CS-R13 and the ablation till samples for sites CS-R14a, -S13a and -S14a. One of the duplicate splits for the basal till sample from site CS-T14 was threshold anomalous in Mo. This suggests that there may be minor occurrences of these elements associated with the southern extremity of the Nashwaak Granite. Elevated values for Be are also associated with the elevated Sn values in this part of the Coldstream map area.

The Nashwaak Lake area and the Deersdale mineral occurrence (URN 1419): As noted by Seaman (2002), the field duplicate samples of basal till from site CS-S02, to the northeast of Nashwaak Lake, are anomalous in Be (6 and 7 ppm), Bi (3.7 and 3.4 ppm) and Sn (8 and 8 ppm). The till from this site is also anomalous in Cs (57 and 57 ppm), Rb (450 and 439 ppm) and Tl (2.3 and 3.0 ppm), and threshold anomalous in K (3.00 and 4.22 %) and Ta (4.7 and 4.1 ppm). To the south and southeast of Nashwaak Lake, there are several sites for which elevated values of Bi, Be or Sn were obtained (Figure 4). Other elements that occur at elevated levels in this area include Ag, Au, Cs, Cu, Hg, Mo, Rb, Ta, Th, Tl, U and some of the rare-earth elements.

As reported by Seaman (2002), the bedrock sample from the Deersdale occurrence (site CS-RK-01-08) contained elevated values for Ag, As, Au, Bi, Hg, Mo, Pb, S, Sb, Tl and W. This occurrence is to the east of the above sites, lying just to the west of column V of the till sample grid, approximately midway between sites CS-V03 and -V04. Pebbles resembling the felsic porphyry at the Deersdale occurrence have been found in several of the pebble samples from sites in the Nashwaak Lake area. This suggests that similar felsic porphyry may be found (beneath till) in the Nashwaak Lake area. The commonality between some of the elements exhibiting elevated values in the bedrock sample and those in some of the till samples to the west supports this suggestion. Also of note is that Lamothe's (1992) highest Au value for the study area (38 ppb) was from his site 87LFA8048, which lies approximately 1 km to the north-northwest of the Deersdale occurrence.

There is no apparent dispersal train extending from the Deersdale mineral occurrence. This may be due to the thickness of the till in the area, which may not permit the detection of dispersed material at the practical depth of hand sampling. An additional possibility is minimal glacial erosion at this site. The exposed section comprised 1.5 to 2 m of soil and basal till overlying shattered bedrock that graded down into sound bedrock. The preservation of the shattered bedrock suggests that the bedrock surface was largely protected from glacial erosion, possibly due to the location of the site on the south (lee) side of a hill.

Further work is planned for the vicinity of the Deersdale mineral occurrence. This will include: sampling of the till at the site, to see if the mineralization is reflected in the basal part of the till; and sampling around the occurrence area to see if short dispersal trains are present similar to those identified in the Sisson Brook area by Snow and Coker (1987).

The Carlisle Formation: Seaman (2001b) noted a strong association between the distribution of elevated values for As, Au, Sb, Sn and W in till and the extent of the Early Carboniferous Carlisle Formation. The association of As, Au and Sb with the Carlisle Formation is evident on Figure 2. Except for W at site CS-K06, there is no longer an apparent association between Sn and W and the Carlisle Formation. This is a result of the significantly higher threshold levels for these elements in the eastern part of the map area compared to those used for the western part of the map area. Seaman (2001b) used a threshold level of 2 ppm for both elements, whereas the threshold level for Sn is 6 ppm for the current study area, and 9 ppm for W (Figure 4). As noted by Seaman (2002), the Carlisle Formation appears to be the dominant source of Au in the study area, with the only anomalous site being CS-H14 (43 ppb average).

The Foreston–Salmon Brook dispersal train, and adjacent site CSL03: A dispersal train of As, Pb and Zn that probably extends from the Foreston (URN 0874) and Salmon Brook (URN 0260) mineral occurrences was reported by Seaman (2001b, 2002). The dispersal train is clearly evident for Pb and Zn on Figure 3. As is no longer evident (Figure 2), again because of the change in threshold level. Seaman (2001b) used a threshold value of 26 ppm, whereas that for the current study is 70.1 ppm (Figure 2).

The geochemical data for site CS-L03 present something of a conundrum. A first glance at Figures 2 and 3 suggests a mix of As, Au and Sb from the Carlisle Formation and Pb and Zn from the Foreston–Salmon Brook dispersal train. However, the values for As, Pb and Sb obtained for the sample from the site suggest that this may not be the case. The As and Sb values (259 ppm and 23.8 ppm, respectively) are two to three times higher than the highest values obtained for till overlying the Carlisle Formation, and are comparable to those obtained for samples from the vicinity of the Lake George Sb mine (Balzer and Seaman 1996; Seaman 2002). Similarly, as noted by Seaman (2002), the Pb value (255 ppm) is higher than previously obtained for any basal till sample from west-central New Brunswick (that did not contain visible galena). It is double the highest value obtained for the sites within the adjacent dispersal train. Given these extremely anomalous values, it is more likely that they represent a local mineralized source than dispersal from more distant sources. As noted above, Seaman (1999b) suggested that several spot anomalies in the part of the Millville map area underlain by the Costigan Mountain Formation reflect local occurrences of mineralization within the formation. Site CSL03 lies within the mapped limits of the Costigan Mountain Formation, and it is suggested that the anomaly may similarly reflect local mineralization, though perhaps of higher grade than previously encountered.

The absence of a south-southeast-trending dispersal train extending from site CS-L03 may be a consequence of the effect of the local topography on the flow of the glacier. The site lies on the northern slope of a short, approximately east–west-trending ridge. As has been suggested by Snow and Coker (1987) for the Sisson Brook area, the compressive flow against the ridge could have induced shearing of bed material into the body of the glacier, preventing the formation of a dispersal train. As noted by Seaman (2002), follow-up sampling is required around the anomaly in an attempt to determine its extent and source.

Other geochemical associations

Correspondence with other mineral occurrences: The till geochemistry data exhibits no anomalies associated with the known McIntosh Brook or Pokiok Brook (north and south) Cu occurrences, or the Becaguimec Lake Cu–Ni occurrence. However, the proportional dot plot for Cu in Seaman (2002) indicates several sites with above average values (in the 39 to 47 ppm range) to the south-southeast of the McIntosh Brook and Pokiok Brook occurrences. The till sample from site CS-P14, to the southeast of the Becaguimec Lake occurrence, also has an above average Cu value (36 ppm). These sub-threshold values probably represent dispersal from these occurrences. The fact that all of these mineral occurrences lie in comparatively narrow stream valleys lying approximately perpendicular to the regional glacial dispersal trend may have limited the viability of glacial erosion in the vicinity of these occurrences.

Geochemical associations with bedrock units: The association of As, Au and Sb with the Carlisle Formation is noted above. Also noted has been Lamothe's (1992) identification of elevated U values associated with the granitic rocks in the eastern part of the current study area. This is confirmed by this study. The higher U values associated with areas underlain by, or down-ice of, the Early Devonian granites is clearly evident on the proportional dot presentation for U in the study area (Figure 5). In addition, Figure 3 illustrates the expected correlation between elevated Co and Ni values and the Becaguimec Gabbro.

Multiple till sites: At two sites in the central part of the study area, two apparently different tills were encountered in stratigraphic superposition. At site CS-N08, the upper unit is a gravelly sandy mud, while

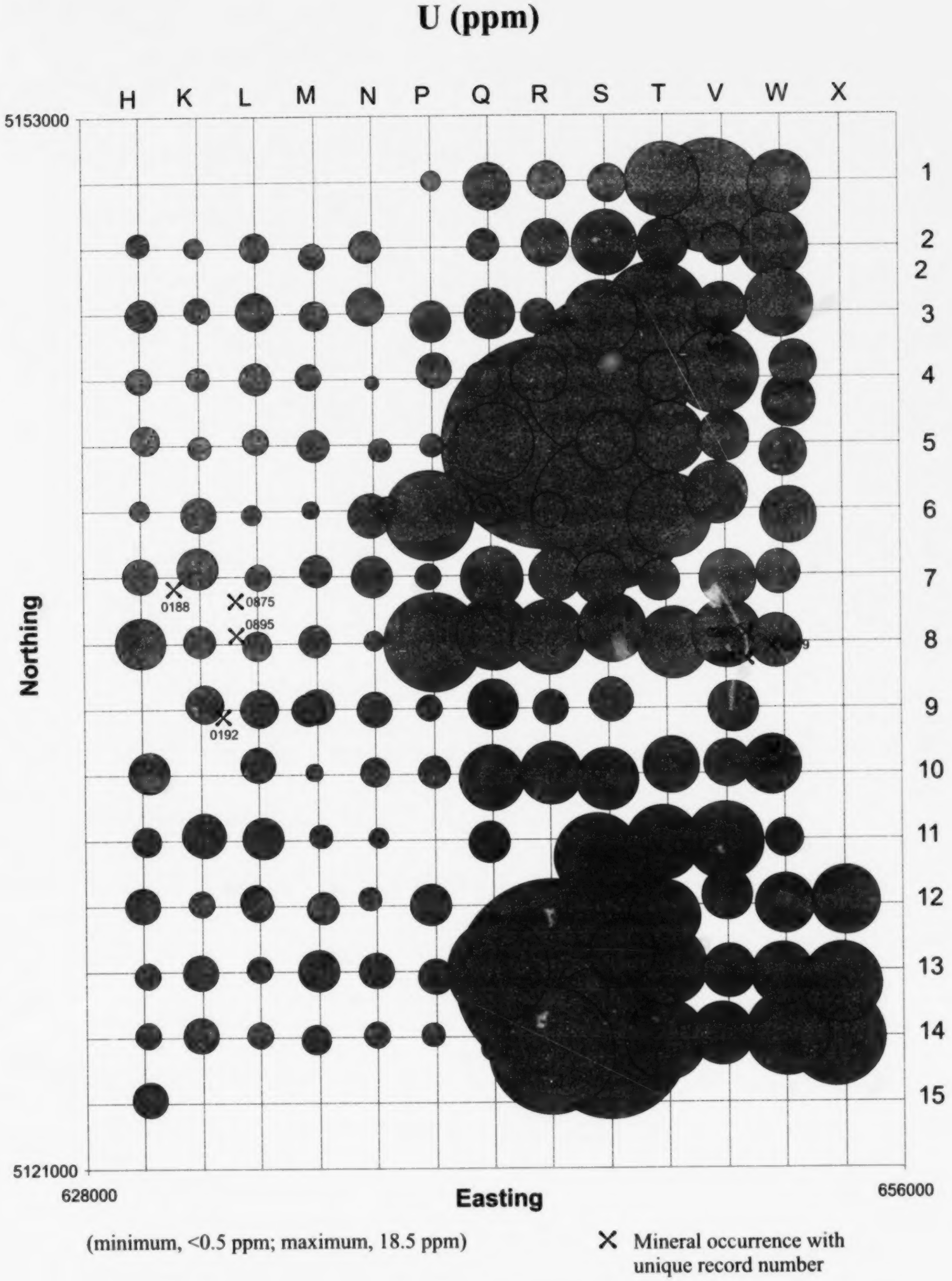

Figure 5. Proportional dot representation of U values in the eastern two-thirds of the Coldstream map area.

the lower unit is an apparently manganiferous, cobbly muddy sandy gravel. At site CS-N11, the upper unit is sandier and less compact that the lower unit. At both sites the colours of the two units are similar. A sample was collected from each unit at each site. For the pair of samples from each site, the percent deviation from the mean value for the two samples was calculated for each of the 51 elements for which results are available (Table 4). These values were summed and then divided by 51 to obtain a value for the overall average percent deviation from the mean. For the pair of samples from site CS-N08 this value was 15.3%, while for the pair of samples from site CS-N11 the equivalent value was 8.8%. The values for the average percent deviation from the mean for the field duplicate samples from the study area are also summarized in Table 4. The overall average percent deviation from the mean for the field duplicate samples is 14.6% for the 51 elements. Since this value is comparable to the overall average values calculated for the two samples from each stratigraphic section, no significant difference between each sample of the pair from either stratigraphic section can be adduced. These results suggest that the apparent difference is a within-till change, i.e., the two apparent units at each site just represent variation within a single till, and that the pair of samples for each site are, in effect, field duplicate samples. A similar observation was made at site MV-Q14 in the adjacent Millville map area, where a reddish brown till unit overlies a yellowish brown unit (Seaman 1999b). Despite the obvious difference in colour, the geochemical, pebble lithology and till fabric data indicate that the section comprises but a single till. For that site, the interpretation is that the till represents south-southeastward glacial flow for a considerable period of time. The lower yellowish brown unit reflects dispersal of material from relatively proximal sources and the transition to the upper reddish brown unit marks the first arrival of material dispersed from the Early Carboniferous Carlisle Formation, approximately 25 km to the north-northwest (Seaman 1999b). A similar explanation may account for the apparent differences noted at the two Coldstream sites.

Alternate basal till sites: For grid points CS-M09 and -N06, samples were collected for two visibly different basal till sites. At site CS-M09a the till is a very dark brown sandy muddy cobble gravel. At site CS-M09b the till is a more compact light olive brown sandy muddy gravel. At site CS-N06a the till is a dark brown gravelly sandy silt, while at site CS-N06b, approximately 0.5 km to the east on the opposite side of a hill, the till is an olive brown gravely sandy mud.

The visible differences between the till at these two pairs of sites for each grid point appears to reflect a geochemical difference. The overall average deviation from the mean for the 51 elements is 28.1% for the pair of sites representing grid point CS-M09, and 25.7% for the pair of sites representing grid point CS-N06 (Table 4). These overall average values are approximately double the value obtained for the field duplicate samples from the study area (Table 4). The sample from site CS-M09a is anomalous in Br, Hg, S, and Se, and threshold anomalous in P. In comparison, the sample from site CS-M09b is below average for Br, P, S and Se, and sub-threshold for Hg. This geochemical difference may reflect the source material for each site, as site CS-M09a lies within the mapped area of one of the felsic units within the Becaguimec Lake gabbro, whereas the till at site CS-M09b overlies the gabbro (observed in outcrop nearby). The sample from site CS-N06a is anomalous in Br, Hg and S, while those from the field duplicate site CS-N06b are below average for these three elements. The reason for the geochemical difference between the till at these two sites is not readily apparent. It may relate to differences in local bedrock geochemistry or to derivation from different source areas, possibly as a result of different glacial transport directions created by the local topography.

Table 4. Values for the Average Percent Deviation from the Mean for Apparent Basal Till Stratigraphic Sections and for Alternate Basal Till Sites

Element	-Average Percent Deviation from the Mean Value-				
	CS-N08-1 and -2	CS-N11-1 and -2	CS-M09a and b	CS-N06a and b	Avg. for Field Duplicates*
Ag	0.0	0.0	38.5	16.7	2.5
Al	50.6	16.1	3.5	8.3	31.1
As	14.4	4.7	31.1	31.6	5.6
Au	60.0	50.0	75.0	71.4	18.4
Ba	2.8	9.7	3.4	2.2	8.7
Be	0.0	0.0	60.0	0.0	10.0
Bi	0.0	0.0	33.3	20.0	12.6
Br	12.1	58.2	93.2	99.3	38.8
Ca	51.7	18.3	30.7	25.9	16.6
Cd	0.0	0.0	0.0	0.0	0.0
Ce	18.8	3.1	15.7	11.1	8.6
Co	8.7	2.8	14.3	17.9	12.2
Cr	4.3	4.8	28.2	19.0	9.5
Cs	16.7	0.0	25.0	36.0	5.2
Cu	12.5	5.4	5.0	2.4	6.3
Eu	13.5	11.8	7.1	1.5	9.9
Fe	2.0	0.6	2.5	4.3	7.1
Ge	20.0	6.7	71.4	42.9	25.9
Hf	23.1	0.0	41.2	0.0	8.0
Hg	6.5	11.1	76.6	50.0	12.7
K	10.9	1.5	44.6	50.9	8.9
La	5.1	10.7	5.4	21.9	9.5
Lu	9.4	8.5	11.7	7.5	9.4
Mg	18.0	12.8	36.6	12.5	15.8
Mn	13.8	2.3	6.9	51.9	6.1
Mo	0.0	0.0	20.0	6.7	20.2
Na	5.9	4.0	36.6	2.9	10.9
Nd	6.9	12.9	22.8	26.9	18.8
Ni	20.3	1.9	35.8	9.3	28.2
P	40.6	6.3	53.4	27.6	13.3
Pb	5.1	11.6	10.3	26.2	9.0
Rb	14.3	10.3	43.1	39.6	6.9
S	34.4	36.8	80.5	82.6	37.6
Sb	5.9	17.6	33.3	51.2	6.1
Sc	3.8	3.1	4.0	7.2	7.5
Se	0.0	23.1	58.3	33.3	27.1
Sm	11.3	11.8	1.5	18.6	15.2
Sn	0.0	0.0	60.0	20.0	6.7
Sr	33.9	4.5	34.4	3.6	16.6
Ta	0.0	0.0	0.0	60.0	28.4
Tb	67.7	10.0	33.3	52.4	51.2
Te	33.3	0.0	0.0	0.0	0.0
Th	0.9	8.8	17.8	17.1	7.0
Ti	0.0	6.7	42.9	12.2	9.4
Tl	14.3	0.0	14.3	29.4	7.7
U	26.3	18.9	6.5	34.5	26.3
V	10.5	8.9	21.6	4.9	5.9
W	0.0	0.0	0.0	80.0	37.6
Y	54.5	4.3	20.0	27.7	30.9
Yb	12.0	8.9	8.1	11.5	10.3
Zn	2.6	0.9	15.9	20.3	7.0
Average	**15.3**	**8.8**	**28.1**	**25.7**	**14.6**

Note: * from Seaman (2002)

CONCLUSIONS

1. The dominant glacial unit in the eastern two-thirds of the Coldstream (NTS 21 J/06) map area is a blanket of basal till generally greater than 0.5 m thick. This till is highly variable in texture and colour, representing the variability in the bedrock units that underlie the area.

2. The distribution of reddish coloured tills from the Early Carboniferous Carlisle Formation indicates an early east-southeastward glacial dispersal event, as previously reported (Seaman 2000). However, as in adjacent areas, the dominant glacial dispersal direction appears to be toward the south-southeast.

3. The largest cluster of sites with anomalous values lies in the eastern part of the study area, in the vicinity of the Sisson Brook, Nashwaak and Manzer Brook mineral occurrences. The distribution of sites with elevated values in this area suggests that the occurrences may relate to a belt of mineralized bedrock approximately parallel to the structural trend, and extending over a distance of about 8 km. However, there is the possibility that some of the length of this apparent belt may relate to southward dispersal from the Sisson Brook occurrences resulting from glacial diversion around Nashwaak Ridge.

4. The single greatest till anomaly in the study area is at site CS-L03, where the As and Sb values are comparable to those in the vicinity of the Lake George Sb mine. The Pb value is also extremely high at this site. Further work is required to attempt to determine the source for this anomaly.

5. The mineralization at the Deersdale occurrence shows no direct correlation with the till geochemistry in the area, possibly due to minimal glacial erosion at the site. However, elevated values for several elements in till in the area around Nashwaak Lake, to the west, may indicate the distribution of similar mineralization over a relatively large area.

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Rhonda Doiron prepared the figures for this report. The paper was critically reviewed by Toon Pronk, P.Geo., and approved for publication by Les Fyffe, Manager of Geological Surveys South.

REFERENCES

Anderson, F.D. 1968. Woodstock, Millville, and Coldstream map-areas, Carleton and York counties, New Brunswick. Geological Survey of Canada, Memoir 353, 69 p.

Balzer, S.A., and Seaman, A.A. 1996. Au, Ag, As, Hg and Sb values in tills of the Canterbury (NTS 21 G/14) map area, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 96-2A.

Folk, R.L. 1968. Petrology of sedimentary rocks. Hemphill's, Austin, Texas, 170 p.

Friske, P.B.W., Pronk, A.G., McCurdy, M.W., Day, S.J.A., McNeil, R.J., and Boldon, R. 2002. Regional stream sediment and water geochemical data, central New Brunswick (NTS 21 J/06 and 21 J/10). Geological Survey of

Canada, Open File 4112, and New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2002-1.

Fyffe, L.R. 1982. Geology, Woodstock. New Brunswick Department of Natural Resources, Mineral Resources Division, Map NR-4.

Fyffe, L.R. 1984. Geological compilation of Coldstream, Carleton & York counties. New Brunswick Department of Natural Resources, Plate 84-307.

Fyffe, L.R., and Fricker, A. 1987. Tectonostratigraphic terrane analysis of New Brunswick. Maritime Sediments and Atlantic Geology, **23**: 113–122.

Hunter, M., and Lavergne, C. 1982. Granular aggregate resources of Coldstream (21 J/6), Napadogan (21 J/7), Hayesville (21 J/10) and Juniper (21 J/11), New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Division, Open File Report 82-2, 209 p.

Kettles, I.M., and Wyatt, P.H. 1986. Reconnaissance geochemical data for till and other surficial sediments, southwestern New Brunswick. Geological Survey of Canada, Open File 1313, 21 p.

Lamothe, M. 1990. Till geochemistry over the southern Miramichi Zone and vicinity, New Brunswick. Geological Survey of Canada, Open File 2238, 77 p.

Lamothe, M. 1992. Pleistocene stratigraphy and till geochemistry of the Miramichi Zone, New Brunswick. Geological Survey of Canada, Bulletin 433, 58 p.

Lutes, G. 1981. Geology of Deersdale–head of Nashwaak River, map-area J-17, and upper parts of Nashwaak River–McBean and Sisters brooks, map-area J-18 (part of 21 J/6). New Brunswick Department of Natural Resources, Mineral Resources, Map Report 81-4, 26 p.

Lutes, G. 1987. Geology and geochemistry of the Pokiok Batholith, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Report of Investigation 22, 55 p.

Merlini, S.A. 1999. New Brunswick computerized mineral occurrence database (revised 1999). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-12.

New Brunswick Department of Natural Resources and Energy. 2000. Bedrock geology of New Brunswick. Minerals and Energy Division, Map NR-1 (2000 edition). Scale 1:500 000.

Rampton, V.N., Gauthier, R.C., Thibault, J., and Seaman, A.A. 1984. Quaternary geology of New Brunswick. Geological Survey of Canada, Memoir 416, 77 p.

Rampton, V.N., and Paradis, S. 1981. Quaternary geology of Woodstock map area (21 J), New Brunswick. New Brunswick Department of Natural Resources, Mineral Development Branch, Map Report 81-1, 37 p.

St. Peter, C. 1982. Geology of Juniper–Knowlesville–Carlisle area, New Brunswick map areas I-16, I-17, and I-18 (parts of 21 J/11 and 21 J/6). New Brunswick Department of Natural Resources, Mineral Resources, Map Report 82-1, 82 p.

Seaman, A.A. 1992. Till geochemistry of part of the Forest City (NTS 21 G/12) map area, York County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources, Open File Report 92-6, 88 p.

Seaman, A.A. 1997. Till geochemistry of the east half of the Millville (NTS 21 J/3) map area, York County, New Brunswick. *In* Current Research 1996. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural

Resources and Energy, Minerals and Energy Division, Mineral Resource Report 97-4, pp. 225–246.

Seaman, A.A. 1998. Till geochemistry of the west half of the Millville (NTS 21 J/3) map area, York and Carleton counties, New Brunswick. *In* Current Research 1997. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 98-4, pp. 75–92.

Seaman, A.A. 1999a. Till geochemistry of the Millville (NTS 21 J/03) map area, York and Carleton counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-11, 85 p.

Seaman, A.A. 1999b. Follow-up till geochemistry in the Millville (NTS 21 J/3) map area, York County, New Brunswick. *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 45–55.

Seaman, A.A. 2000. Glacial dispersal in west-central New Brunswick. Atlantic Geology, **36**: 71–72.

Seaman, A.A. 2001a. Preliminary report – till geochemistry of part of the west half of the Coldstream (NTS 21 J/06) map area, Carleton and York counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2001-2, 51 p.

Seaman, A.A. 2001b. The Cloverdale As–Sb dispersal train, and other till geochemical anomalies in the west half of the Coldstream (NTS 21 J/06) map area, Carleton and York counties, New Brunswick. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 97–110.

Seaman, A.A. 2002. Till geochemistry of the central and eastern parts of the Coldstream (NTS 21 J/06) map area, York and Carleton counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals, Policy and Planning Division, Open File 2002-5, 80 p.

Snow, R.J., and Coker, W.B. 1987. Overburden geochemistry related to W–Cu–Mo mineralisation at Sisson Brook, New Brunswick, Canada: An example of short- and long-distance glacial dispersal. Journal of Geochemical Exploration, **28**: 353–368.

Venugopal, D.V. 1982. Geology of upper parts Becaguimec, Keswick and Nashwaak rivers–Cloverdale–Millville map-areas I-19, J-19, J-20 (parts of 21 J/3, 21 J/6). New Brunswick Department of Natural Resources, Mineral Resources, Map Report 82-2, 35 p.

THE UPSALQUITCH–DUNGANNON Zn–Pb–Ag–Cu OCCURRENCE, BATHURST MINING CAMP, NEW BRUNSWICK (NTS 21 O/08W) †

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WALKER, J.A. 2002. The Upsalquitch–Dungannon Zn–Pb–Ag–Cu occurrence, Bathurst Mining Camp, New Brunswick (NTS 21 O/08W). *In* Current Research 2001. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division; Mineral Resources Report 2002-4, pp 105–127.

The Upsalquitch–Dungannon Zn–Pb–Ag–Cu occurrence comprises low-grade vein and disseminated sulphides hosted by an intercalated sequence of chlorite- to sericite-altered ash- and quartz-crystal tuff of the Nepisiguit Falls Formation. Sulphide mineralization is dominantly pyrrhotite with subordinate pyrite and minor sphalerite, galena and chalcopyrite. Combined Pb + Zn assays reach a maximum of 4.0 wt. %. The mineralized zone has been drill tested over a short strike length of approximately 200 m and has been intersected to depths of 120 m with widths up to 30 m. The zone is open at depth and along strike.

The high pyrrhotite content in this occurrence suggests a possible co-genetic link with disconformable, stringer-type mineralization at the Devils Elbow and TV Tower sulphide bodies. Elevated Eu and depleted Nb are consistent with high-temperature (> 350° C), stringer-zone-style hydrothermal alteration.

La venue de Zn–Pb–Ag–Cu d'UpsalquitchDungannon est constituée d'un filon à faible teneur et de sulfures disséminés inclus dans une séquence intercalée de tuf cinéritocristallin et quartzo-cristallin chloritisé à séricitisé de la Formation de Nepisiguit Falls. La minéralisation sulfurée est principalement constituée de pyrrhotine accompagnée d'une quantité inférieure de pyrite et de quantités modestes de sphalérite, de galène et de chalcopyrite. Les teneurs combinées en Pb + Zn atteignent un maximum de 4,0 % poids. La zone minéralisée a fait l'objet de sondages d'exploration sur un intervalle de 200 mètres le long de son axe et on a recoupé des largeurs pouvant atteindre 30 mètres à des profondeurs de 120 mètres. La zone est ouverte en profondeur ainsi que le long de son axe.

La teneur élevée en pyrrhotine de cette venue permet de supposer un lien cogénétique possible avec la minéralisation à faisceau de filonnets discordante du coude Devils et les masses de sulfures du secteur du pylône de télévision. Les concentrations élevées d'Eu et la pauvreté en Nb correspondent à une altération hydrothermale de type zone de faisceau de filonnets de température élevée (> 350 °C).

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† New Brunswick Geological Surveys Branch ordinary budget.

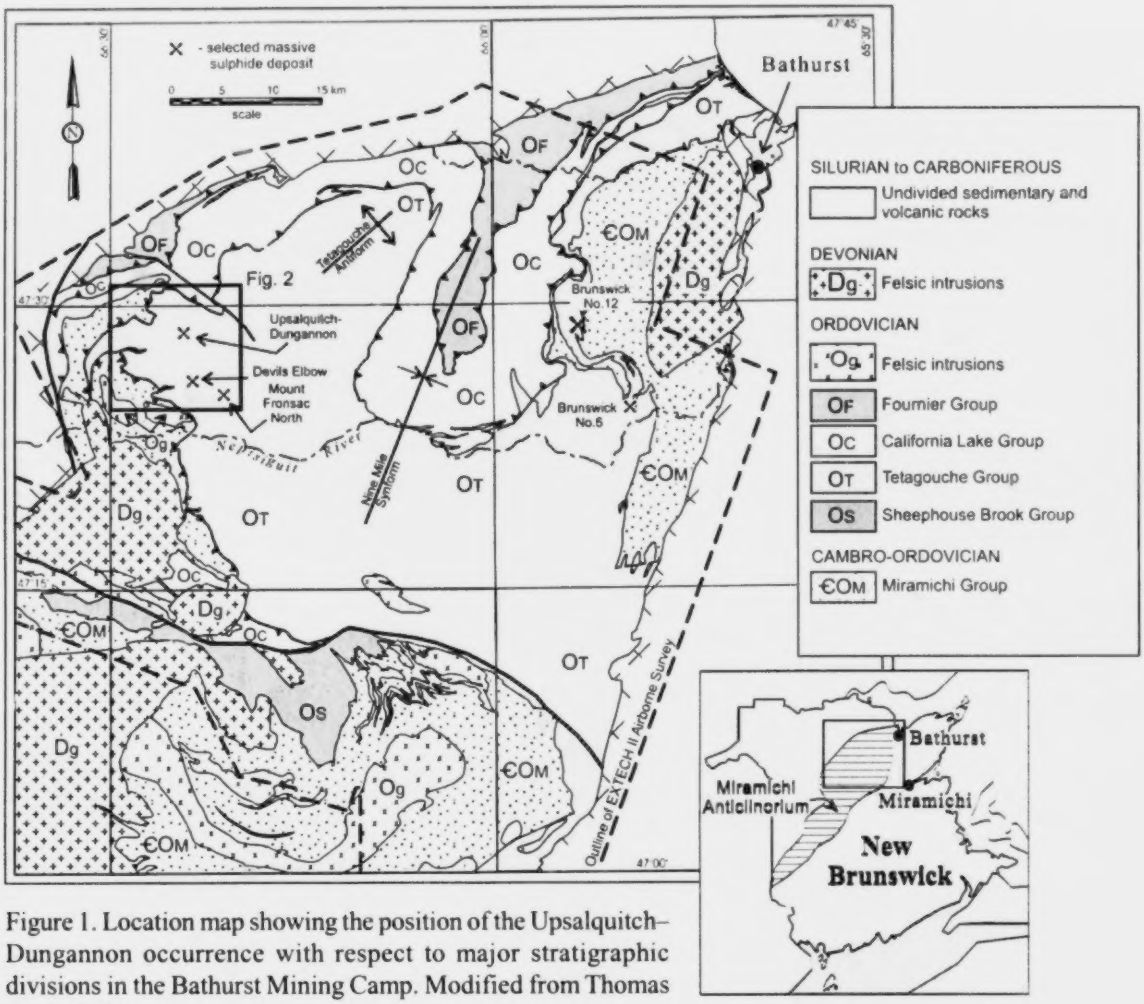

Figure 1. Location map showing the position of the Upsalquitch–Dungannon occurrence with respect to major stratigraphic divisions in the Bathurst Mining Camp. Modified from Thomas *et al.* (2000).

INTRODUCTION

The Upsalquitch–Dungannon Zn–Pb–Cu occurrence (New Brunswick Unique Record Number [URN] 0416) lies in the western part of the Bathurst Mining Camp, approximately 50 km west-southwest of the city of Bathurst and 6 km south of the abandoned Murray Brook mine (Figures 1 and 2).

A detailed study of this occurrence was undertaken because of its proximity to two significant volcanogenic massive sulphide deposits, namely Devils Elbow (Walker 1997) and Mount Fronsac North (Walker and Graves, in preparation), 4.8 km south-southeast and 7 km southeast, respectively. The host rocks, mineralization and alteration associated with this occurrence were documented in order to formulate exploration models for additional sulphide deposits in this part of the Bathurst Mining Camp. This was accomplished by relogging cores from drill holes CDC-96-1, UPS-78-2, and UPS-78-4 (Figure 2), and by collection and analysis of a series of lithogeochemical and petrographic samples from these cores.

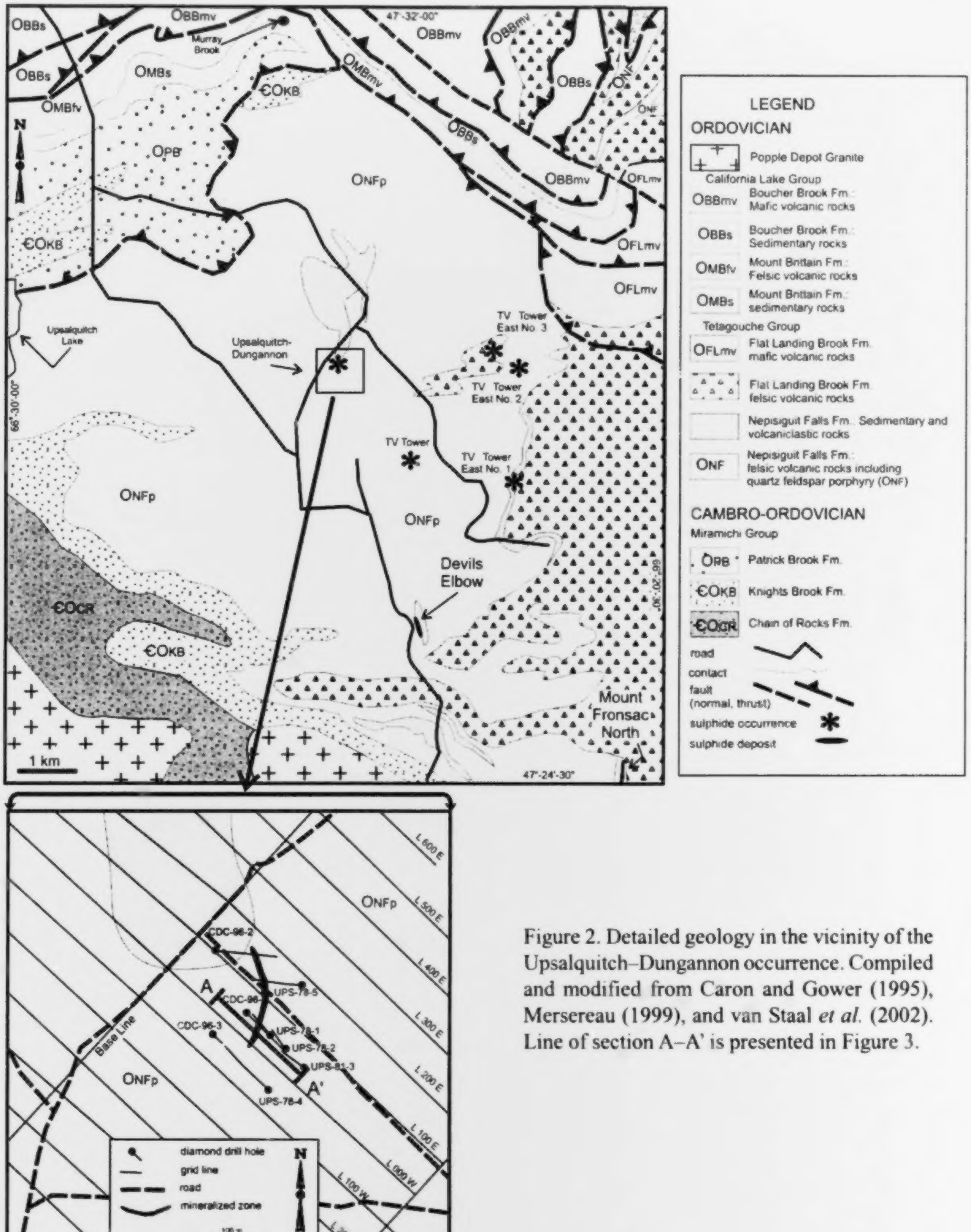

Figure 2. Detailed geology in the vicinity of the Upsalquitch–Dungannon occurrence. Compiled and modified from Caron and Gower (1995), Mersereau (1999), and van Staal *et al.* (2002). Line of section A–A' is presented in Figure 3.

Discovery and exploration history

The western part of the Bathurst Mining Camp has received little exploration attention relative to the better-explored Brunswick–Heath Steele belt in the east, despite the fact that significant massive sulphide bodies have been discovered, e.g., Mount Fronsac North, Murray Brook (Figure 2) and Restigouche (4 km west of the area outlined on Figure 2). The more important exploration work conducted in and around the occurrence is summarized as follows.

The Upsalquitch–Dungannon occurrence was discovered by follow-up drilling (Gummer 1979, drill hole UPS-78-4; von Guttenberg1979, drill holes UPS-78-1, -78-2, -78-5) of an airborne geophysical anomaly (Gummer 1977). Several ground geophysical surveys have been conducted on and around the Upsalquitch–Dungannon occurrence, including Max-Min, magnetometer, and VLF-EM surveys. Two areas with coincident magnetometer and Max-Min anomalies were outlined (von Guttenberg 1981a). Magnetometer and VLF-EM surveys that were conducted immediately east of the Upsalquitch–Dungannon area are reported in von Guttenberg (1981b).

Huxhold (1981a) reported the results of VLF-EM, magnetometer, and soil geochemistry surveys and subsequent diamond drilling of one hole (UPS-81-2). The hole was collared several hundred metres north-northeast of the Upsalquitch–Dungannon occurrence and intersected disseminated pyrite and pyrrhotite. Results of VLF-EM, Mise-a-la-Masse, and IP surveys as well as diamond drilling (3 holes: UPS-81-1, -81-3, -81-4) are summarized in Huxhold (1981b). Drill holes UPS-81-1 and -81-4 were drilled approximately 1400 m southeast of the Upsalquitch–Dungannon occurrence.

The most recent work in the area is reported in Mersereau (1999) and includes VLF-EM, Max-Min, magnetometer and soil geochemical surveys, and diamond drilling (2 drill holes: CDC-96-01 and -96-02). A small gravity survey was also conducted and shows a 0.5 to 0.8 mgal anomaly coincident with the area of known mineralization, which extends several hundred metres to the north. However, the gravity coverage is not complete and extension of the grid to the north–south and east–west was recommended.

REGIONAL GEOLOGY

The Bathurst Mining Camp comprises a poly-deformed Middle Ordovician sequence of bimodal volcanic and intercalated sedimentary rocks deposited in a back-arc basin that formed on Cambro-Ordovician siliciclastic rocks (flysch sequence) bordering a stable peri-Gondwanan continental margin (van Staal and Fyffe 1991). As currently understood (Figure 1), the Bathurst Mining Camp comprises five groups, namely, the Miramichi, Sheephouse Brook, Tetagouche, California Lake and Fournier groups (see Wilson *et al.* 1998; Thomas *et al.* 2000; and van Staal *et al.*, in press, and references therein for detailed descriptions). The Miramichi Group includes Cambro-Ordovician siliciclastic rocks, whereas the Fournier Group is dominated by ocean floor mafic volcanic rocks. The three remaining groups, i.e., Sheephouse Brook, Tetagouche, and California Lake groups, all contain felsic and mafic volcanic and sedimentary rocks.

During closure of the back-arc basin in the Late Ordovician to Early Silurian, the rocks of the Bathurst Mining Camp were dismembered and deformed in a subduction-related accretionary prism. The resulting tectonostratigraphic relationships among map units are invariably complex to the point that at least five generations of folding are evident (McCutcheon *et al.* 1993; van Staal 1994). However, in general terms the Bathurst Mining Camp can be divided into four major thrust nappes that internally contain numerous stratigraphic cut-outs and/or repetitions related to subsidiary thrust faults.

The Bathurst Mining Camp is a world class volcanogenic massive sulphide camp that contained a pre-mining geologic resource of 349 000 000 t of massive sulphide (McCutcheon *et al.*, in press). Since the discovery of the Brunswick No. 6 ore body in 1952 (Belland 1992), the Bathurst Mining Camp has produced more than 134 000 000 t of massive sulphide ore grading 3.05% Pb, 7.82% Zn, 0.46% Cu and 91.5 g/t Ag (McCutcheon *et al.*, in press). There are 46 known volcanogenic massive sulphide (VMS) deposits in the Bathurst Mining Camp and all are spatially associated with felsic volcanic rocks (McCutcheon *et al.* 2001). Nine deposits have reached either production or an advanced stage of preproduction development; the most famous of which is the currently producing Brunswick Mining and Smelting No. 12 mine (> 290 000 000 t of massive sulphide resource), located 25 km southwest of Bathurst (Figure 1). The majority of these deposits (32 of 46), are hosted by the Tetagouche Group, with 24 associated with the Nepisiguit Falls Formation and the remainder associated with the stratigraphically higher Flat Landing Brook Formation (McCutcheon *et al.* 2001). Chemically precipitated iron-formation overlies, and is laterally continuous with, many of the deposits hosted by the Nepisiguit Falls Formation. In contrast, iron formation is absent or poorly developed in deposits hosted by the Flat Landing Brook Formation.

DETAILED GEOLOGY

For the purpose of this paper, only those units occurring within the thrust slice that hosts the Upsalquitch–Dungannon occurrence will be described. Descriptions of units occurring outside the host nappe in Figure 2 can be found in the references listed in the previous section. According to regional mapping by Caron and Gower (1995), Gower (1995), Gower and McCutcheon (1995), and van Staal *et al.* (2002) the thrust nappe that hosts the Upsalquitch–Dungannon occurrence contains rocks of the Tetagouche Group and the conformably underlying Miramichi Group (Figure 2).

Miramichi Group

The Miramichi Group crops out south of the Upsalquitch–Dungannon occurrence and comprises two formations, namely, the Chain of Rocks and Knights Brook formations. The Chain of Rocks Formation is the older of the two and contains fine- to medium-grained, grey quartzite interbedded with greenish grey slate (Gower 1995). The Knights Brook Formation conformably overlies the Chain of Rocks Formation and is dominated by dark grey to black, locally graphitic shale interbedded with volcaniclastic rocks and quartz-rich sandstone (Gower 1995).

Tetagouche Group

The Tetagouche Group underlies the majority of the study area (Figure 2), and is divided into two formations, namely the Nepisiguit Falls and Flat Landing Brook formations.

Nepisiguit Falls Formation: This formation predominantly comprises a thick sequence of quartz-phyric and quartz–feldspar-phyric crystal tuff, ash tuff and related volcaniclastic rocks. Thin beds of mudstone and fine-grained wacke occur locally within the Nepisiguit Falls Formation. With few exceptions, these units are too thin and discontinuous to be differentiated on maps of 1:20 000 scale or smaller (Figure 2).

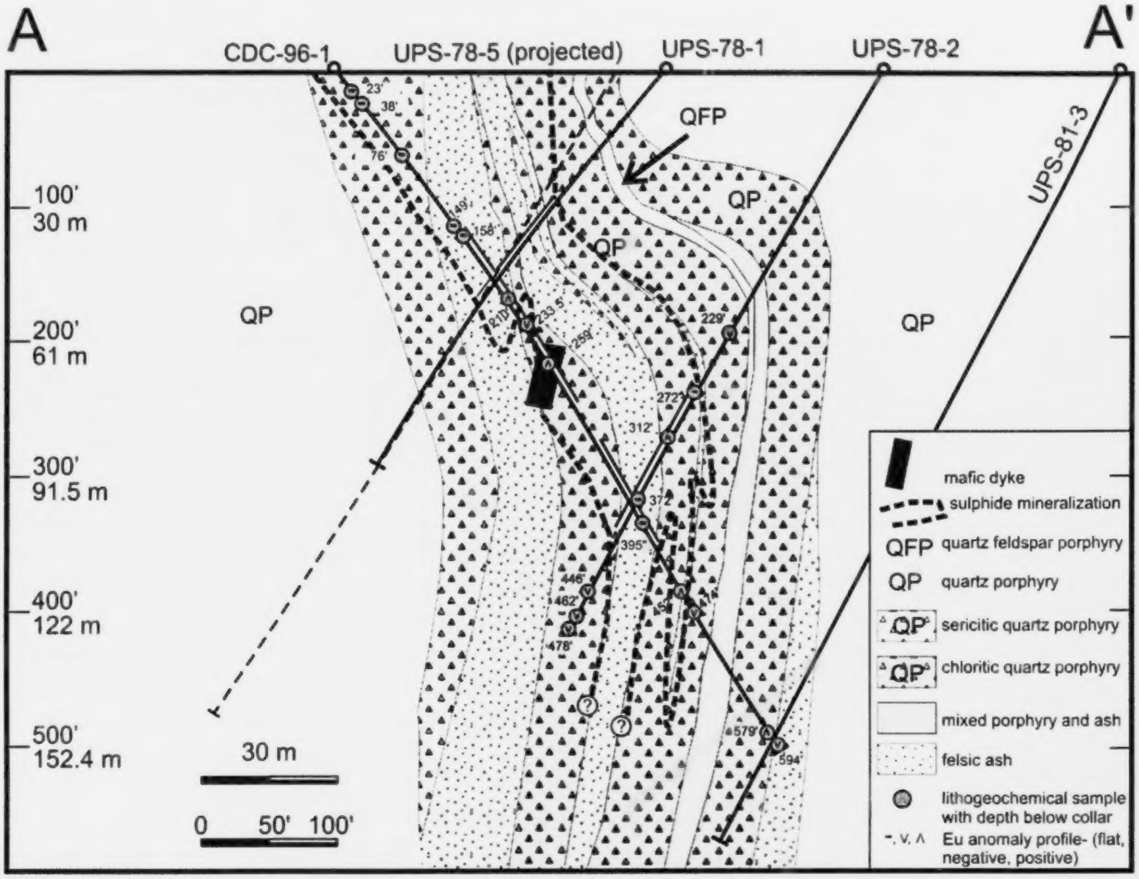

Figure 3. Geological section through the Upsalquitch–Dungannon zone. Line of section A–A' is located on Figure 2. Geology modified from Mersereau (1999). Filled circles (○) correspond to sample locations for data presented in Table 1.

In those areas where sedimentary horizons are thick enough to map, they appear to occur at, or near, the boundary between the volcanic rocks of the Nepisiguit Falls Formation and overlying rhyolites of the Flat Landing Brook Formation to the east (Caron and Gower 1995; Gower 1995; Walker, 1997). One such accumulation of sedimentary rocks was mapped less than 200 m to the north of the Upsalquitch–Dungannon occurrence by Caron and Gower (1995). However, the thickness and stratigraphic position of this unit with respect to the Nepisiguit Falls–Flat Landing Brook contact are less well understood than the sedimentary units to the east (Figure 2).

All rocks at the Upsalquitch–Dungannon occurrence (Figures 2 and 3), except for a late mafic dyke (see below), are assigned to the Nepisiguit Falls Formation and consist of dominantly quartz-phyric crystal tuff (Figure 4a). The intensity of deformation in these rocks is such that they are for the most part mineralogically segregated, with monomineralic quartz layers alternating with quartz + white mica layers (Figure 4b). Sulphides (mostly pyrite and pyrrhotite) and opaque Fe-oxide minerals (probably secondary) occur locally. Similar porphyritic rocks in the Devils Elbow area were the topic of a Ph.D. thesis by

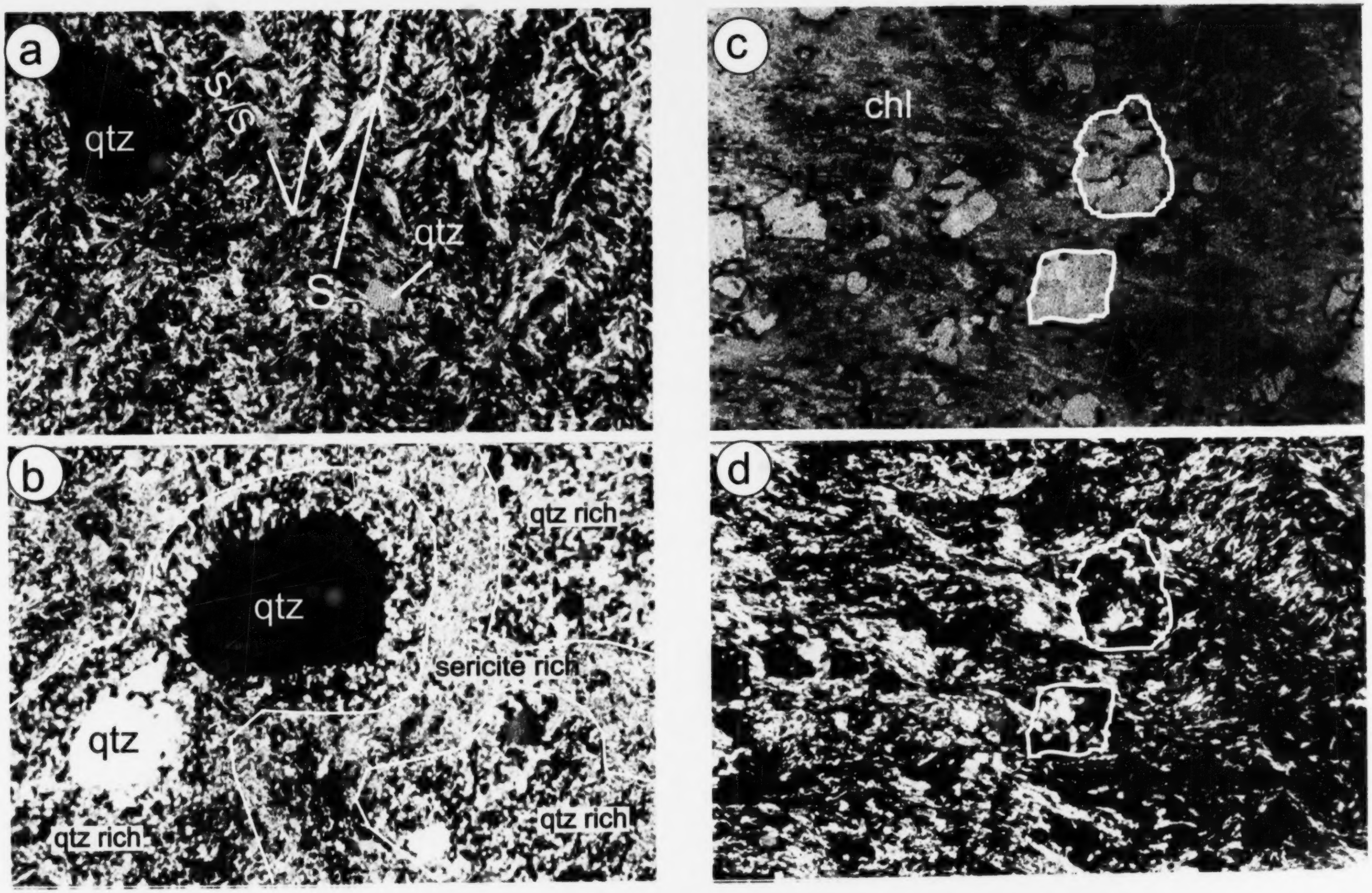

Figure 4. Photomicrographs of major rock types at the Upsalquitch–Dungannon Pb–Zn occurrence. (a) deformed quartz-phyric tuff of the Nepisiguit Falls Formation (sample UPS-78-2-312'; under crossed polars). Note relatively undeformed quartz (qtz) phenocrysts in a strongly deformed groundmass of white mica and fine-grained quartz. Two fabrics (S_1/S_2 and S_3) are evident in the groundmass. (b) typical quartz crystal-tuff of the Nepisiguit Falls Formation (sample UPS-78-2-229'; under crossed polars). Note deformation-induced mineralogically segregated zones of inner quartz and outer sericite + quartz, concentric about larger quartz phenocrysts. (c) chlorite-altered feldspar(?)-phyric mafic dyke (sample CDC-96-1-259'; plane polarized light). (d) same as (c) but with crossed nicols. Note the "disappearance" of the phenocrysts, which are replaced by a complex intergrowth of quartz–sericite–chlorite. Field of view in all figures is 5.45 mm.

Louden (1960), who interpreted them as ignimbrites. Subsequent work in the Brunswick belt and elsewhere (McCutcheon 1992 and others) has shown that they are highly variable with volcaniclastic, pyroclastic, and hypabyssal magmatic components.

Locally, some thin units of fine-grained, aphyric, quartz–sericite-rich rocks are interlayered with the quartz porphyritic rocks. These fine-grained units are interpreted as ash tuffs (Figure 3), and are chemically indistinguishable from the porphyritic rocks (see section on lithogeochemistry).

Some of the porphyritic rocks in the Upsalquitch–Dungannon area contain quartz phenocrysts or "eyes" that have an atypical blue colour as noted by Mersereau (1999); and von Guttenberg (1979). Quartz eyes of similar colour have been observed in the Devils Elbow area, 4 km to the south. Petrographic examination of samples with blue quartz grains failed to explain this coloration. However, abundant chlorite with blue birefringence is present in some samples, and may be responsible for the apparent blue coloration of adjacent quartz grains. The proximity of blue quartz eyes to mineralization and associated chloritic alteration does seem to support this hypothesis.

Flat Landing Brook Formation: This formation conformably overlies the Nepisiguit Falls Formation and comprises light grey to buff, aphyric- to sparsely feldspar-phyric rhyolite flows and domes, and related hyaloclastite and/or pyroclastic rocks. An isolated mass of rhyolite occurs within the Nepisiguit Falls Formation immediately to the east of the Upsalquitch–Dungannon occurrence (Figure 2).

Within the Flat Landing Brook Formation, east of the area outlined in Figure 2, units of mafic volcanic rock (Forty Mile Brook Member) are interlayered with felsic volcanic rocks. Similar rocks were intersected in drilling at the Upsalquitch–Dungannon occurrence (see lithogeochemistry section and Figures 4c and 4d).

Popple Depot Granite: The Popple Depot Granite crops out approximately 6.5 km south of the deposit (Figure 2), where it occupies the core of an anticline underlain mainly by rocks of the Miramichi Group (Gower 1995). This intrusion comprises pink to grey, equigranular, foliated to massive, fine- to medium-grained, biotite granite (Gower 1995), that has yielded a U/Pb zircon age of 474 ± 4 Ma (Gower 1996). The upper age limit of the Popple Depot Granite suggests emplacement was contemporaneous with deposition of the Nepisiguit Falls Formation, i.e., 469 ± 2 Ma (van Staal and Sullivan 1992). Contemporaneous intrusions are commonly invoked as heat engines to drive massive sulphide-forming hydrothermal systems (Franklin *et al.* 1981; and others). However, in the case of this intrusion there is no evidence to link it directly with the mineralization at the Upsalquitch–Dungannon occurrence or the Devils Elbow deposit (Walker 1997).

Structural Geology: Deformation in the host rocks is intense, as evidenced by the metamorphic differentiated layering described above. Additionally, undulatory extinction (locally present in quartz phenocrysts), numerous triple-point grain boundary intersections, and alignment and folding of phyllosilicates (Figure 4a) all signify strong deformation.

The study area is included in a structural domain known as the "flat belt" (de Roo and van Staal 1994). In this area, the dominant fabric is a composite schistosity comprising early S_0/S_1 and S_2 fabrics that formed during F_1 thrusting and upright isoclinal F_2 folding, respectively. Early $S_0/S_1/S_2$ composite fabric is re-oriented by recumbent F_3 folds that have a well-developed, flat-lying S_3 cleavage. These two fabrics are more or less mutually perpendicular and similar to those described in Walker (1997) and Walker and Graves (in preparation). Map patterns suggest that, in general, the Nepisiguit Falls–Flat Landing Brook contact strikes north–south in this area but may locally be east–west (Figure 2). The change in strike is probably a function of the interference between isoclinal F_2 folds and recumbent F_3 folds with a possible input from $F_{4\text{-}5}$ folds.

The paucity of outcrop in the study area makes structural interpretation difficult. To the southeast, in the Mount Fronsac North–Devils Elbow area, drill hole coverage and outcrop distribution reveal a complex fold interference pattern. The same interference patterns are undoubtedly present in the Upsalquitch–Dungannon area.

Sulphide deposits and occurrences

Several occurrences of base-metal sulphides and accompanying chloritic alteration lie within 3.5 km to the east and south of the Upsalquitch–Dungannon occurrence (Figure 2). These include the TV Tower, and TV Tower East # 1, #2 and #3 occurrences (URN 284, 1285, 1286 and 1287, respectively, in Rose and Johnson 1990). The TV Tower occurrence is dominated by pyrite–pyrrhotite mineralization with minor Cu–Pb–Zn sulphides and, like the Devils Elbow deposit, is quite similar in style to the Upsalquitch–Dungannon occurrence. The other occurrences are dominated by pyrite ± minor pyrrhotite and Pb–Zn sulphides, and are associated with intensely chloritized sedimentary rocks.

LITHOGEOCHEMISTRY

A suite of samples (n=20) from two diamond-drill holes (CDC-96-1 and UPS-78-2) was collected as part of this study and the samples were analyzed at Activation Laboratories, Ancaster, Ontario. The results of these analyses, along with analytical methods and detection limits, are listed in Table 1, and the sample locations relative to stratigraphy are presented in Figure 3.

Major and trace element data

The effects of greenschist-grade metamorphism and hydrothermal alteration preclude the use of alkali elements for the use of protolith determination (Lentz and Goodfellow 1993). Consequently, high-field-strength elements (HFSE) are used for this purpose because of their relative immobility under the conditions prevailing in the Bathurst Mining Camp (Lentz and Goodfellow 1992; Lentz 1996).

The sample suite shows a wide range in K_2O contents with values that range between 1.5 and 9.8 wt. %, whereas Na_2O values are much lower and restricted to a range of 0.01 to 0.28 wt. %. The high K_2O values occur in samples that have a large component of white mica that probably formed by hydrothermal alteration of K-feldspar.

The SiO_2 contents of these rocks are highly variable and range between 44 and 82 wt. %. This variability is attributed to a combination of factors, including precipitation and or dissolution of quartz (temperature dependent) from hydrothermal fluids in various parts of the system.

One of the more useful trace-element discrimination diagrams for the determination of protolith of an altered rock is the Nb/Y versus Zr/TiO_2 diagram (Figure 5a). Most of the samples from the Upsalquitch–

Table 1. Lithogeochemical Data from the Upsalquitch–

Sample Name	**Analytical Method**	**Detection Limit**	**CDC-96-1-0023**	**CDC-96-1-0038**	**CDC-96-1-0076**	**CDC-96-1-0149**	**CDC-96-1-0158**	**CDC-96-1-0210**	**CDC-96-1-0233.5**	**CDC-96-1-0259**	**CDC-96-1-0395**
Rock Description			QP-ser, sulphides	QP-ser, sulphides	QP-ser. sulphides and FeO's	qtz-ser ash, minor sulphides	felsic ash, minor sulphides	qtz-ser ash	QP-ser	mafic dyke	qtz-ser ash + sulphides
(wt %)											
SiO_2	ICP	0.01	55.62	51.56	70.78	46.12	82.54	80.54	69.36	62.20	79.00
TiO_2	ICP	0.01	0.28	0.24	0.29	0.45	0.53	0.15	0.28	0.73	0.09
Al_2O_3	ICP	0.01	13.41	14.58	13.94	21.71	8.17	9.03	15.69	14.18	4.90
Fe_2O_3	ICP	0.01	14.94	18.56	4.37	14.33	2.36	4.01	4.23	11.29	7.87
MgO	ICP	0.01	0.75	1.93	0.79	1.06	0.44	0.72	0.95	5.01	0.25
MnO	ICP	0.01	0.01	0.13	0.03	0.02	0.01	0.02	0.03	0.18	0.01
CaO	ICP	0.01	< 0.01	0.10	0.16	0.26	0.07	0.10	0.19	0.12	0.13
Na_2O	ICP	0.01	0.16	0.18	0.19	0.24	0.12	0.11	0.19	0.11	0.11
K_2O	ICP	0.01	3.16	2.92	4.45	7.15	2.74	2.91	5.07	2.04	1.51
P_2O_5	ICP	0.01	0.16	0.18	0.15	0.22	0.06	0.08	0.16	0.10	0.11
S	ICP	0.01	8.90	8.33	1.99	9.33	0.79	1.39	0.09	0.13	6.88
LOI	ICP	0.01	10.44	8.21	5.01	8.61	1.59	2.14	2.47	4.19	4.59
TOTAL			98.93	98.60	100.16	100.18	98.65	99.81	98.62	100.14	98.57
(ppm) *											
Ag	ICP	0.5	1.4	1.1	0.6	0.4	0.4	< 0.3	< 0.3	< 0.3	< 0.3
As	INAA	1	5	26	12	3	1	1	< 1	126	72
Au (ppb)	INAA	1	8	20	4	2	2	< 2	2	< 2	2
Ba	ICP	1	142	161	175	323	129	203	204	86	51
Be	ICP	1	2	1	2	3	1	2	2	1	< 1
Bi	ICP	0.10	0.1	1.1	0.1	< 0.1	0.1	< 0.1	0.7	2.4	0.3
Cd	ICP	0.5	0.4	4.4	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Co	INAA	0.1	8.4	20.9	5.7	5.7	2.4	4.1	2.2	42.5	6.4
Cr	INAA	0.5	14.1	11.2	11.2	14.6	41.7	10.8	11.6	310	12.3
Cs	ICP/MS	0.2	1.3	1.4	2.2	3.1	1.5	2.0	2.5	1.5	0.9
Cu	ICP	1	587	548	110	345	48	210	212	15	313
Ga	ICP/MS	1	18	21	23	38	14	14	23	16	7
Ge	ICP/MS	1	< 0.5	0.7	0.7	0.6	0.7	0.7	1.0	1.0	0.8
Hf	ICP/MS	0.2	5.6	4.4	5.4	8.5	4.0	2.6	5.4	2.4	1.5
In	ICP/MS	0.1	0.2	0.2	0.3	0.2	< 0.1	0.1	0.3	-0.1	< 0.1
Mo	INAA	2	< 2	7	7	5	< 2	3	4	< 2	< 2
Nb	ICP/MS	0.2	7.8	4.3	8.4	12.8	6.5	1.5	7.4	0.5	-0.2
Ni	ICP	1	30	12	4	6	7	7	< 1	170	8
Pb	ICP	5	542	671	53	28	41	23	10	15	13
Rb	ICP/MS	2	140	135	210	300	128	135	218	108	70
Sb	INAA	0.1	4.5	3.2	1.5	2.8	1.5	3.8	2.2	50.2	5.2
Sc	INAA	0.01	4.5	4.9	5.1	8.6	8.2	3.5	5.6	26.8	1.8
Se	INAA	0.5	< 0.5	8.6	0.8	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Sn	ICP/MS	1.0	9	13	37	6	12	17	36	11	12
Sr	ICP	2	12	16	18	26	12	9	21	8	8
Ta	ICP/MS	0.3	1.07	0.78	1.08	1.70	0.77	0.51	1.01	0.32	0.31
Th	ICP/MS	0.1	14.6	12.5	14.7	22.4	7.53	7.11	14.6	4.00	4.52
Tl	ICP/MS	0.05	0.16	0.67	1.08	0.61	0.63	0.95	1.66	0.74	0.41
U	ICP/MS	0.05	6.71	4.94	11.0	7.84	2.16	2.73	5.35	1.18	1.76
V	ICP	5	16	17	18	30	53	27	19	148	13
W	INAA	1	4	8	12	14	4	3	3	11	2
Y	ICP	1	48	43	35	90	26	14	45	28	15
Zn	ICP	1	416	501	196	55	56	82	57	175	39
Zr	ICP	1.0	177	138	177	254	146	81	164	83	48
La	ICP/MS	0.05	40.5	32.1	30.2	48.7	19.4	8.49	30.3	6.05	11.6
Ce	ICP/MS	0.10	87.0	70.7	67.0	104	44.8	18.8	67.6	17.6	24.7
Pr	ICP/MS	0.02	9.77	8.05	7.67	12.1	5.04	2.16	7.78	2.56	2.82
Nd	ICP/MS	0.05	39.8	33.4	31.2	49.9	20.6	8.71	31.6	12.7	11.4
Sm	ICP/MS	0.01	8.05	7.18	6.31	10.6	3.68	1.86	6.57	3.44	2.42
Eu	ICP/MS	0.001	2.52	2.71	1.81	2.82	1.11	0.852	1.51	2.06	0.824
Gd	ICP/MS	0.02	7.59	7.14	6.17	10.8	3.25	1.88	6.33	3.71	2.33
Tb	ICP/MS	0.10	1.44	1.33	1.17	2.27	0.59	0.39	1.26	0.78	0.45
Dy	ICP/MS	0.02	9.03	7.77	6.99	14.6	3.62	2.46	7.83	4.89	2.70
Ho	ICP/MS	0.01	1.84	1.54	1.43	3.12	0.81	0.53	1.60	0.98	0.55
Er	ICP/MS	0.01	5.28	4.07	3.90	8.91	2.54	1.53	4.53	2.71	1.51
Tm	ICP/MS	0.005	0.796	0.560	0.574	1.35	0.409	0.238	0.667	0.374	0.219
Yb	ICP/MS	0.01	4.69	3.38	3.36	7.70	2.56	1.43	3.89	2.28	1.29
Lu	ICP/MS	0.002	0.634	0.472	0.496	1.03	0.400	0.214	0.559	0.339	0.176

Notes: Analytical methods: ICP – inductively coupled plasma emission spectrometry; ICP/MS – inductively coupled plasma/mass spectrometry;
* All values in ppm unless otherwise stated.

Dungannon Sulphide Occurrence, NTS 21 O/08W

CDC-96-1-0452	CDC-96-1-0474	CDC-96-1-0579	CDC-96-1-0594	UPS-78-2-0229	UPS-78-2-0272	UPS-78-2-0312	UPS-78-2-0372	UPS-78-2-0446	UPS-78-2-0462	UPS-78-2-0472
QP-chlorite + ser	QP-chlorite + ser	QP-chloritic	QP-chloritic	QP-ser	QP-ser	QP-Ser	QP-chloritic + sulphides	QP-ser	QP-ser	QP-ser
69.37	55.98	68.70	61.28	72.61	44.84	73.99	52.83	68.65	74.23	72.62
0.26	0.44	0.25	0.21	0.25	0.68	0.26	0.31	0.19	0.22	0.37
14.98	21.99	12.65	13.34	11.99	29.67	13.31	15.17	11.55	11.03	13.58
5.87	6.88	8.48	11.95	5.34	6.15	2.89	19.78	11.03	6.77	3.35
1.85	2.48	3.37	6.43	1.87	1.73	0.84	2.78	1.67	0.99	0.84
0.06	0.09	0.06	0.08	0.06	0.07	0.03	0.18	0.10	0.05	0.02
0.16	0.21	0.21	0.19	0.16	0.70	0.16	0.20	0.21	0.13	0.25
0.15	0.18	0.10	0.11	0.14	0.28	0.23	0.20	0.13	0.13	0.13
4.47	7.02	2.79	1.82	3.57	9.63	4.43	3.38	2.32	2.85	7.15
0.13	0.17	0.17	0.14	0.13	0.27	0.13	0.16	0.11	0.11	0.16
0.05	0.02	0.01	0.01	0.51	0.05	0.96	4.82	0.40	0.03	0.02
2.86	3.82	3.01	4.24	2.54	4.81	2.29	5.19	2.75	2.00	1.71
100.17	99.25	99.81	99.78	98.66	98.81	98.55	100.17	98.73	98.52	100.18
< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	0.7	4.2	< 0.3	< 0.3	< 0.3	< 0.3
< 1	4	13	13	14	13	8	10	5	6	4
< 2	3	< 2	< 2	5	< 2	< 2	2	3	2	2
509	681	186	120	250	1287	225	116	216	355	1650
2	4	1	1	2	4	2	1	1	1	1
< 0.1	2.4	0.2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	8.9	0.2
< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
4.4	6.4	14.2	20.6	9	4.5	2.8	4.9	9.9	9.8	5.7
9.8	10.7	11.4	8.8	11.6	18.9	9	11.2	9.1	9.5	14.3
2.3	3.4	0.9	0.7	1.6	4.3	2.2	1.9	1.1	1.5	1.3
11	5	7	6	67	37	12	279	68	7	7
22	32	18	21	18	39	19	24	19	18	20
0.9	1.1	1.0	1.3	0.9	1.2	0.5	0.9	0.9	1.0	1.1
5.6	8.8	5.0	4.4	4.5	13.3	4.7	6.0	3.5	4.0	5.9
< 0.1	0.3	0.2	0.1	0.3	0.3	< 0.1	0.1	< 0.1	0.1	< 0.1
< 2	< 2	< 2	< 2	3	7	< 2	< 2	< 2	< 2	3
4.5	14.2	6.4	5.7	6.4	22.3	6.6	9.8	4.4	5.1	8.1
5	4	6	5	4	2	3	2	3	3	5
3	4	< 3	12	28	< 3	42	13	-3	7	3
205	319	119	82	168	407	215	155	98	131	204
4	5.1	1.9	1.7	3.5	9.3	39.6	1.9	2.7	1.6	0.9
6	8.3	5.1	4.3	4.7	12.5	5	5.4	3.5	3.8	7.2
< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
11	33	49	14	23	77	10	9	12	26	9
14	17	7	5	9	30	17	17	10	11	45
1.05	1.64	0.94	0.86	0.87	2.40	0.91	1.14	0.84	0.89	1.12
15.1	23.6	14.2	11.5	12.2	36.4	13.6	15.3	10.4	11.6	15.0
1.49	2.39	0.49	0.42	1.34	4.51	4.03	0.89	0.62	0.92	0.50
3.25	8.42	5.71	6.29	5.18	11.3	4.90	5.66	4.03	3.68	4.72
24	29	18	17	14	41	21	15	13	13	32
3	7	7	6	4	9	3	4	3	2	6
39	58	40	37	24	96	42	43	35	33	37
110	78	55	53	126	108	313	171	39	20	15
171	268	155	134	146	395	149	192	107	132	194
37.3	48.2	33.3	26.9	24.6	74.9	30.4	33.8	32.1	25.8	38.9
82.3	107	72.8	58.7	56.1	163	66.7	73.4	71.5	58.0	85.8
9.32	12.3	8.27	6.69	6.31	18.8	7.65	8.41	8.05	6.53	9.83
38.3	50.0	33.4	27.1	25.4	76.2	31.0	34.4	32.4	25.9	38.2
7.60	10.1	6.93	5.58	5.08	15.0	6.26	6.96	6.87	5.51	7.71
0.971	4.51	0.610	0.466	0.496	3.86	3.85	1.95	1.20	1.09	1.54
6.96	9.72	6.45	5.36	4.64	14.2	5.96	6.61	6.24	5.30	7.04
1.31	1.84	1.21	1.07	0.86	2.60	1.13	1.25	1.19	1.00	1.26
7.74	11.1	7.27	6.58	4.86	15.8	7.14	7.72	6.65	6.16	7.13
1.54	2.26	1.51	1.34	0.92	3.34	1.54	1.60	1.29	1.27	1.42
4.29	6.40	4.25	3.83	2.56	9.65	4.30	4.60	3.48	3.48	3.96
0.633	0.931	0.662	0.593	0.394	1.46	0.621	0.699	0.502	0.532	0.589
3.63	5.75	3.64	3.40	2.37	8.68	3.66	4.10	2.87	2.98	3.45
0.492	0.807	0.516	0.479	0.368	1.28	0.501	0.584	0.395	0.405	0.498

INAA – instrumental neutron activation analysis. Rock types: QP – quartz-phyric tuff-lava; ser – sericite; chl – chlorite.

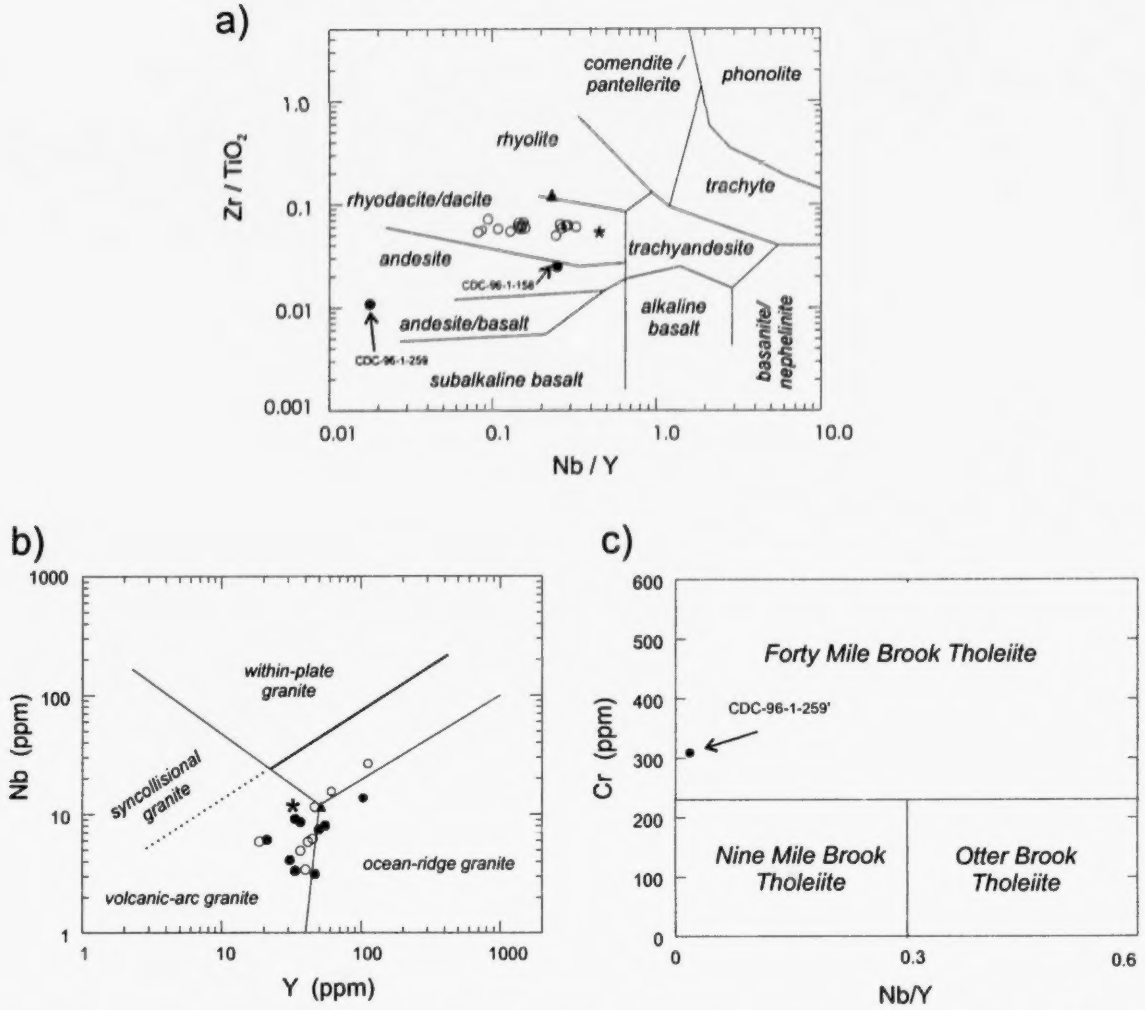

Figure 5. Lithogeochemical discrimination diagrams for Upsalquitch–Dungannon samples listed in Table 1. (a) Nb/Y versus Zr/TiO_2 diagram; field boundaries from Winchester and Floyd (1977); (b) Y versus Nb tectonic discrimination diagram, after Pearce *et al.* (1984). The triangle (▲) and asterisk (*) are the Flat Landing Brook and Nepisiguit Falls averages, respectively, of Langton and McCutcheon (1993); (c) Nb/Y versus Cr discrimination diagram for mafic rocks in the Bathurst Mining Camp, after van Staal *et al.* (1991) showing composition of mafic dyke sample CDC-96-1-259'. In all figures, the filled circles (●) are from the structural footwall and the open circles (○) are from the structural hanging wall (see Figure 3).

Dungannon occurrence plot in a tight cluster in the middle to lower parts of the rhyodacite–dacite field on this diagram, over a very narrow range of Zr/TiO_2, similar to Nepisiguit Falls Formation rocks from the eastern part of the Bathurst Mining Camp (Lentz and Goodfellow 1992; Lentz 1996), and the Devils Elbow area (Walker 1997). The Zr/TiO_2 for the suite is similar to the Nepisiguit Falls average of Langton and McCutcheon (1993), and noticeably lower than the value for the Flat Landing Brook average of Langton and McCutcheon (1993).

On a Nb versus Y tectonic discrimination diagram (Figure 5b), the majority of the Upsalquitch–Dungannon samples fall within the volcanic-arc field (even though the rocks formed in a back-arc basin), typical of Nepisiguit Falls rocks elsewhere in the Bathurst Mining Camp. However, the Upsalquitch–Dungannon samples plot slightly lower on the Nb axis than expected. Similar low Nb values have been recognized in the footwall stringer zone of the Halfmile Lake deposit and have been attributed to hydrothermal alteration processes (Adair 1992). Similar hydrothermal processes may have been active at the Upsalquitch–Dungannon occurrence.

Regional mapping by Gower (1995) indicates that hydrothermal alteration is widespread in this part of the Bathurst Mining Camp. For example, hydrothermal alteration is well developed to the east and northeast of the Devil's Elbow deposit, near the contact with the overlying Flat Landing Brook Formation (Gower, personal communication). The felsic volcanic rocks intersected in diamond-drill holes at the Upsalquitch–Dungannon occurrence are notable for their complete lack of feldspar. Elsewhere in the Camp, the absence of feldspar has been attributed to the effects of hydrothermal alteration (Lentz and Goodfellow 1993).

One sample (CDC-96-1-259') has anomalously high Co (42.5 ppm), Cr (310 ppm), Ni (170 ppm), and V (148 ppm), and low U (1.18 ppm), Th (4.0 ppm), and Zr/TiO_2 (0.01). All of these chemical indicators point to an intermediate to mafic affinity for this sample. This is confirmed by its position in the andesite/basalt field on the Nb/Y versus Zr/TiO_2 diagram (Figure 5a). On the Nb/Y versus Cr diagram (Figure 5c), this sample plots in the Forty Mile Brook tholeiitic basalt field of van Staal *et al.* (1991). Petrographic analysis has shown this sample to be composed of feldspar phenocrysts (30 %) in a mostly chlorite matrix (Figure 4c). However, unlike the quartz phenocrysts in the more felsic samples, the pseudomorphed feldspar phenocrysts are completely replaced by complex intergrowths of quartz and chlorite (Figure 4d).

Rare-earth-element data

Chondrite-normalized rare-earth-element data for the Upsalquitch–Dungannon occurrence (Table 1) can be divided into three populations. The first is characterized by strong to moderately negative Eu anomalies, with an average Eu/Eu* = 0.27 (n=8) (Figure 6a). The La_n/Lu_n ratio for this population is 6.96. Fractionation of Eu into plagioclase and the subsequent removal of feldspar from the system (i.e., crystal fractionation) is commonly invoked as the most likely mechanism for depletion of Eu. This profile is common for all unaltered felsic volcanic rocks in the Bathurst Mining Camp.

The second population (n=8) includes samples lacking Eu anomalies, i.e., slightly negative to slightly positive (Figure 6b). In this population the average Eu/Eu* = 1 and the average La_n/Lu_n= 6.06. The third population (n=3) includes those samples with slight to moderately positive Eu anomalies (Figure 6c). The average Eu/Eu* = 2.15, and the average La_n/Lu_n ratio is approximately 5.5.

The reason for the variation in Eu contents between sample sets 1 through 3 is somewhat unclear as the samples in all three populations are petrographically similar and have similar ΣREE contents and Zr/TiO_2 and TiO_2/Al_2O_3 ratios (Figures 7a and 7b), which suggest that these rocks formed from a similar magma.

Sample CDC-96-1-259' has a low La_n/Lu_n ratio of 1.84, and also has a positive Eu anomaly with an Eu/Eu* value of approximately 2.6. The overall flat profile is typical of mid-ocean-ridge-basalt-type basalts, but the positive Eu is atypical (Rollinson 1995). One possible explanation for the Eu enrichment in this sample is the abundant (plagioclase?) phenocrysts. Consequently, large amounts of early-formed plagioclase in a sample could yield rare-earth-element profiles that are anomalously enriched in Eu. An alternative to this interpretation will be discussed in the next section.

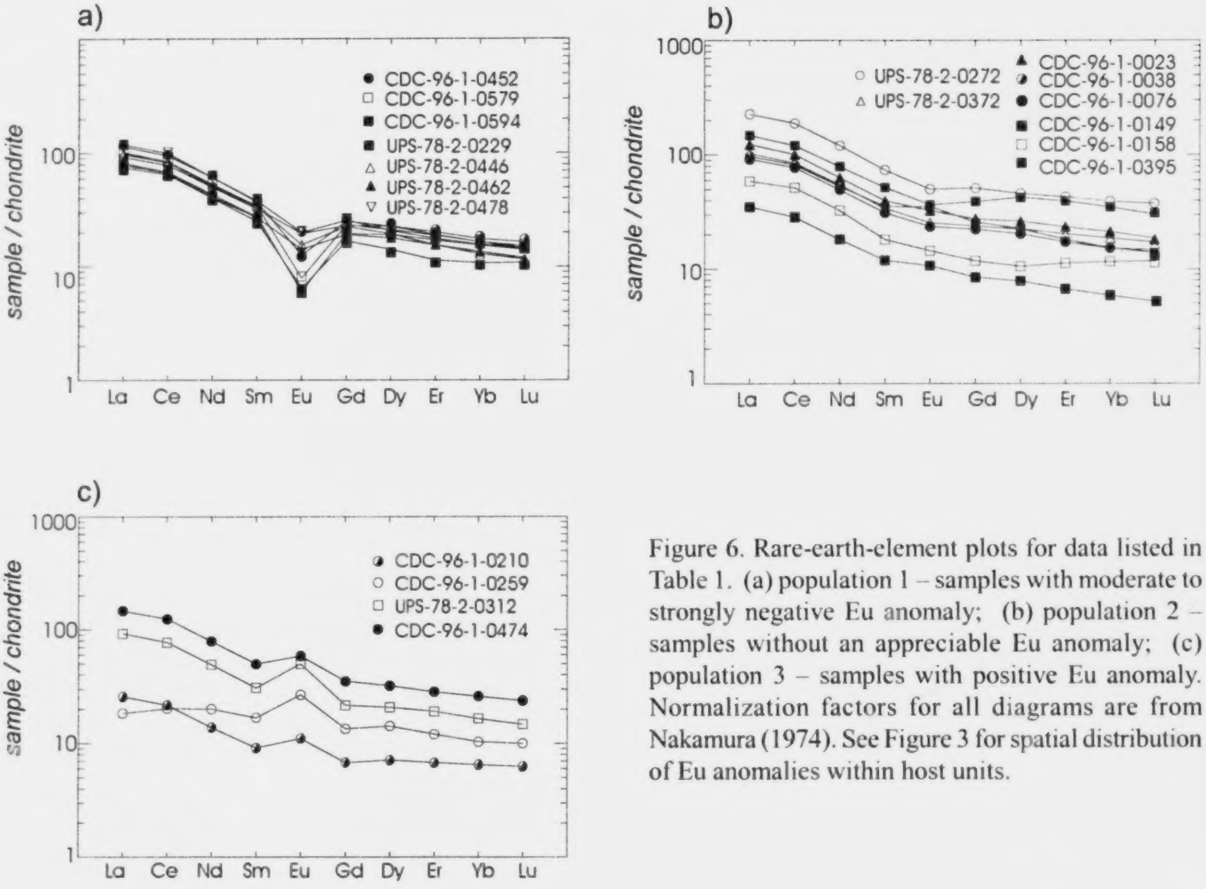

Figure 6. Rare-earth-element plots for data listed in Table 1. (a) population 1 – samples with moderate to strongly negative Eu anomaly; (b) population 2 – samples without an appreciable Eu anomaly; (c) population 3 – samples with positive Eu anomaly. Normalization factors for all diagrams are from Nakamura (1974). See Figure 3 for spatial distribution of Eu anomalies within host units.

Hydrothermal Alteration

In order to determine the net mass loss or mass gain of various major elements in the Upsalquitch–Dungannon alteration envelope, the data in Table 1 were normalized to Al_2O_3 using the Nepisiguit Falls average of Langton and McCutcheon (1993). The resulting recalculated compositions were compared to the Nepisiguit Falls average to obtain a mass change for various major elements (see Leitch and Lentz 1994).

Alteration at the Upsalquitch–Dungannon occurrence is similar to that in other deposits of the Bathurst Mining Camp. Chlorite is spatially associated with the better-developed pyrrhotite zones, whereas sericite is more distal. Mass-recalculated data presented in Figures 7c to 7e show that there is a net increase in Fe and Mg accompanying a depletion in Na and K, and supports the observed dominance of chlorite alteration over sericite in most of these rocks. Most of these rocks have a net mass decrease in SiO_2 accompanying the increase in Fe + Mg and the decrease in (K + Na). A few samples show a net mass gain in SiO_2 that may be attributed to quartz veining in the vent system (Figure 8).

There is a crude zoning with respect to Eu content about the sulphide-bearing zone at the Upsalquitch–Dungannon occurrence (Figure 3). Within the sulphide-bearing envelope, Eu is typically enriched

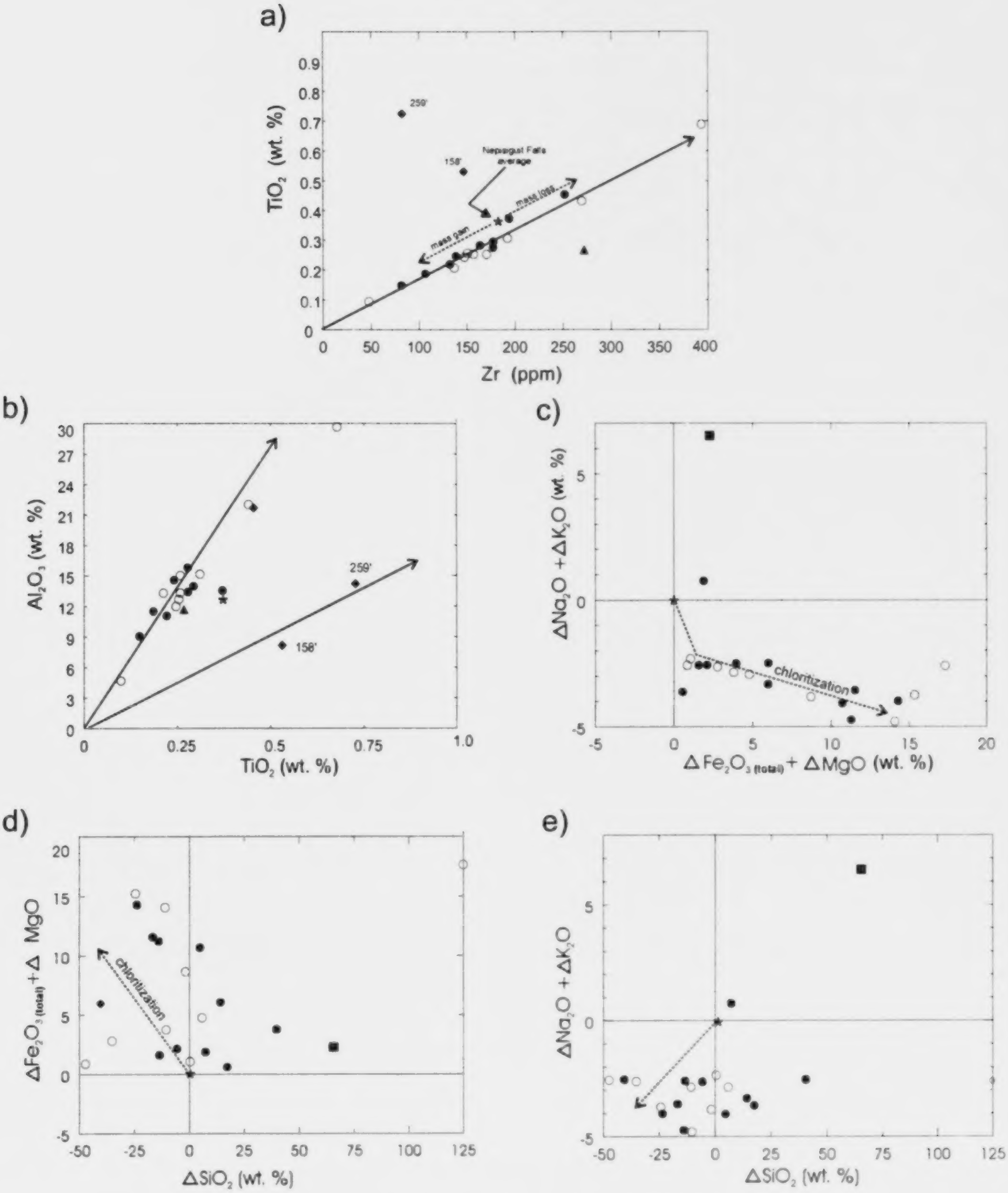

Figure 7. Alteration diagrams. (a) Zr versus TiO$_2$ (raw data) showing apparent mass gain or mass loss with respect to the Nepisiguit Falls average; (b) TiO$_2$ versus Al$_2$O$_3$ (raw data) trends for felsic rocks and mafic rocks (labeled diamonds ◆); (c) mass change diagram for (Fe$_2$O$_3$ + MgO) versus (Na$_2$O + K$_2$O); (d) mass change diagram for SiO$_2$ versus Fe$_2$O$_3$ + MgO; (e) mass change diagram for SiO$_2$ versus Na$_2$O + K$_2$O. For all figures, filled circles (●) are from the structural footwall and open circles (○) are from the structural hanging wall (see Figure 3). The triangle (▲) and asterisk (*) are the Flat Landing Brook and Nepisiguit Falls averages, respectively, of Langton and McCutcheon (1993).

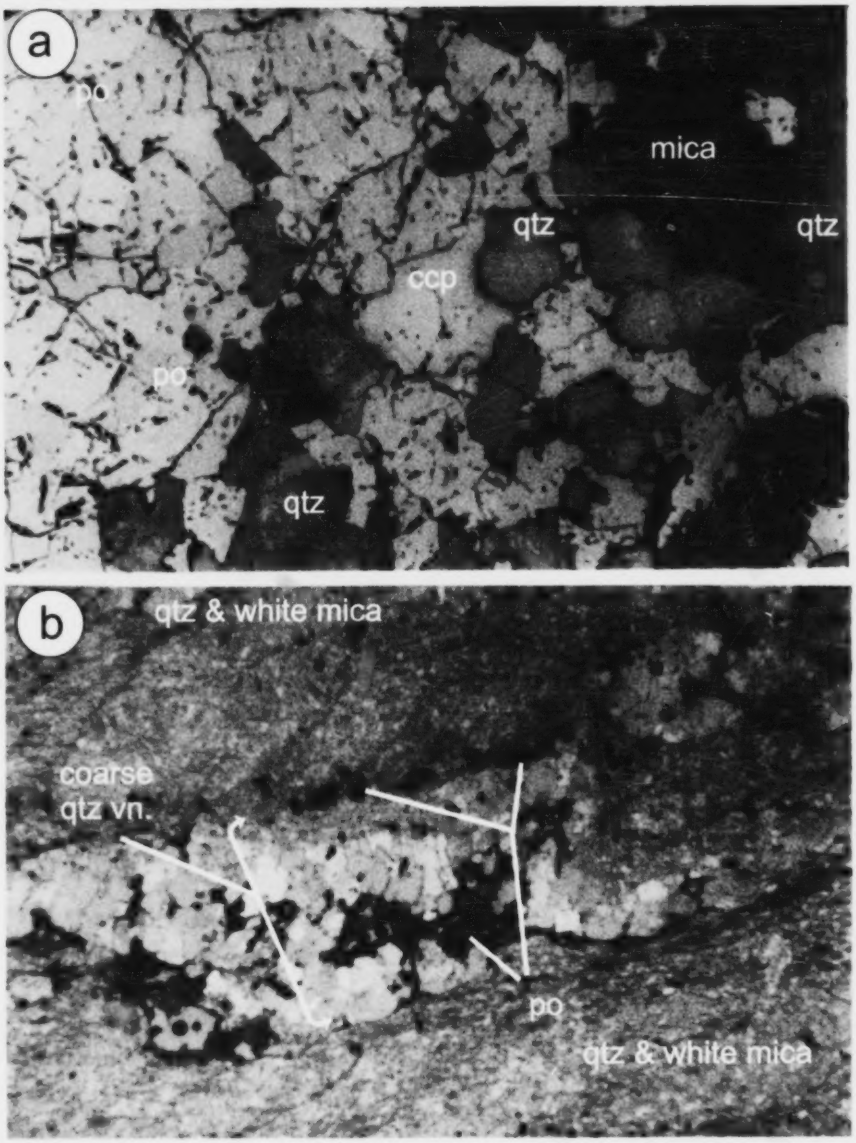

Figure 8. Photomicrographs of sulphide mineralization. (a) pyrrhotite (po) and minor chalcopyrite (ccp) in altered quartz porphyry (sample CDC-96-1-158'); (b) quartz–pyrrhotite vein cutting an altered felsic volcanic rock consisting of fine-grained quartz–sericite. Vein is approximately 1.2 mm across (sample CDC-96-1-254'). The field of view in both figures is 5.45 mm.

(Eu/Eu* > 1), whereas immediately adjacent to the sulphide zone, in sericitically altered rocks, Eu anomalies are absent (Eu/Eu* H" 1). Outboard from the mineralized zones Eu is commonly depleted (Eu/Eu* < 1), as in typical felsic volcanic rocks. In many volcanogenic massive sulphide (VMS) deposits, Eu is depleted in the footwall and enriched in the massive sulphide lens or immediate hanging wall, resulting in an asymmetrical profile. Positive Eu anomalies are also associated with sulphide-bearing exhalite rocks in the Bathurst Mining Camp, e.g., Graf (1977), Adair (1992), Walker and Graves (in preparation). This is attributed to rare-earth-element solubility under conditions of high temperature (< 350° C) and low pH, as at VMS vent sites (Gale *et al.* 1997). The symmetrical zonation of Eu in the Upsalquitch–Dungannon occurrence might be interpreted to represent the combined effects of temperature zonation and variable water–rock ratios about an inclined hydrothermal conduit. The core of this conduit is marked by a high-temperature sulphide assemblage (i.e., pyrrhotite + chalcopyrite, and chlorite), which formed during the prograde stage of the system. As the system waned and isotherms retreated, Eu was deposited in those areas where the temperature dropped below 350° C.

SULPHIDE MINERALIZATION AND ZONATION

Sulphide mineralogy at the Upsalquitch–Dungannon occurrence is typical of volcanogenic massive sulphide deposits throughout the Bathurst Mining Camp. Pyrite is dominant with significant pyrrhotite; sphalerite, galena and chalcopyrite are also present, yielding grades of up to 4% combined Pb + Zn over a width of 2 m, and 1.2 % Pb + Zn over widths up to 40 m (von Guttenberg 1979). However, the style of mineralization is not typical of a massive-layered stratiform-type volcanogenic massive sulphide deposit in the Bathurst Mining Camp. Rather, sulphide mineralization tends to be disseminated or associated with quartz veins, and less commonly as remobilized patches. Locally, pyrrhotite is the dominant sulphide (> 90% of sulphide in most sections), with lesser amounts of pyrite, sphalerite and galena (rarely exceeding 10 % combined), and occasional trace grains of chalcopyrite and arsenopyrite (<< 1%). Like most other deposits hosted by the Tetagouche Group (McClenaghan 2002), Au values at the Upsalquitch–Dungannon occurrence are elevated but not particularly high (maximum 20 ppb in Table 1).

The mineralized zone has been tested by 8 diamond-drill holes and has been intersected to depths of 120 m, over true widths up to 30 m. Overall the zone strikes north–south and is very steeply east-dipping (Figures 2 and 3). All of the available assay data for the occurrence (n=216) are plotted on a Pb–Cu–Zn ternary diagram (Figure 9a), which displays a clustering of data points along the Pb–Zn axis at approximately 65–75% Zn. This Pb–Zn ratio is typical of the stratiform parts of Bathurst Camp deposits and indeed of volcanogenic massive sulphide deposits worldwide (Franklin *et. al.* 1981). Figure 9a also shows a wide scatter of data points over the reminder of the figure. This scatter reflects sampling of pyrrhotite–chalcopyrite zones and may also be an artifact of the generally low grade Pb–Zn mineralization throughout the deposit.

Metal zonation trends that are typical of volcanogenic massive sulphide deposits elsewhere are not evident at the Upsalquitch–Dungannon occurrence. Profiles of Cu, Pb, and Zn assay data relative to depth are presented for drill holes UPS 78-1 and UPS 78-2 (Figure 9b). These profiles show that Zn and Pb covary positively. Interestingly, Cu varies positively with Pb and Zn, rather then inversely as is typical. This relationship may be the result of overprinting prograde pyrrhotite–chalcopyrite mineralization on an earlier lower temperature sphalerite–galena–pyrite assemblage.

CONCLUSIONS

The Upsalquitch–Dungannon sulphide occurrence consists of stringer-type mineralization hosted entirely within quartz-phyric and aphyric rocks of the Nepisiguit Falls Formation. Immediately north of the occurrence is a package of sedimentary rocks, which is also assigned to the Nepisiguit Falls Formation. The position of the occurrence with respect to the Nepisiguit Falls–Flat Landing Brook contact is unknown. The entire host sequence is intensely deformed and displays a mineralogical segregation with chlorite predominant to the southeast and white mica to the northwest.

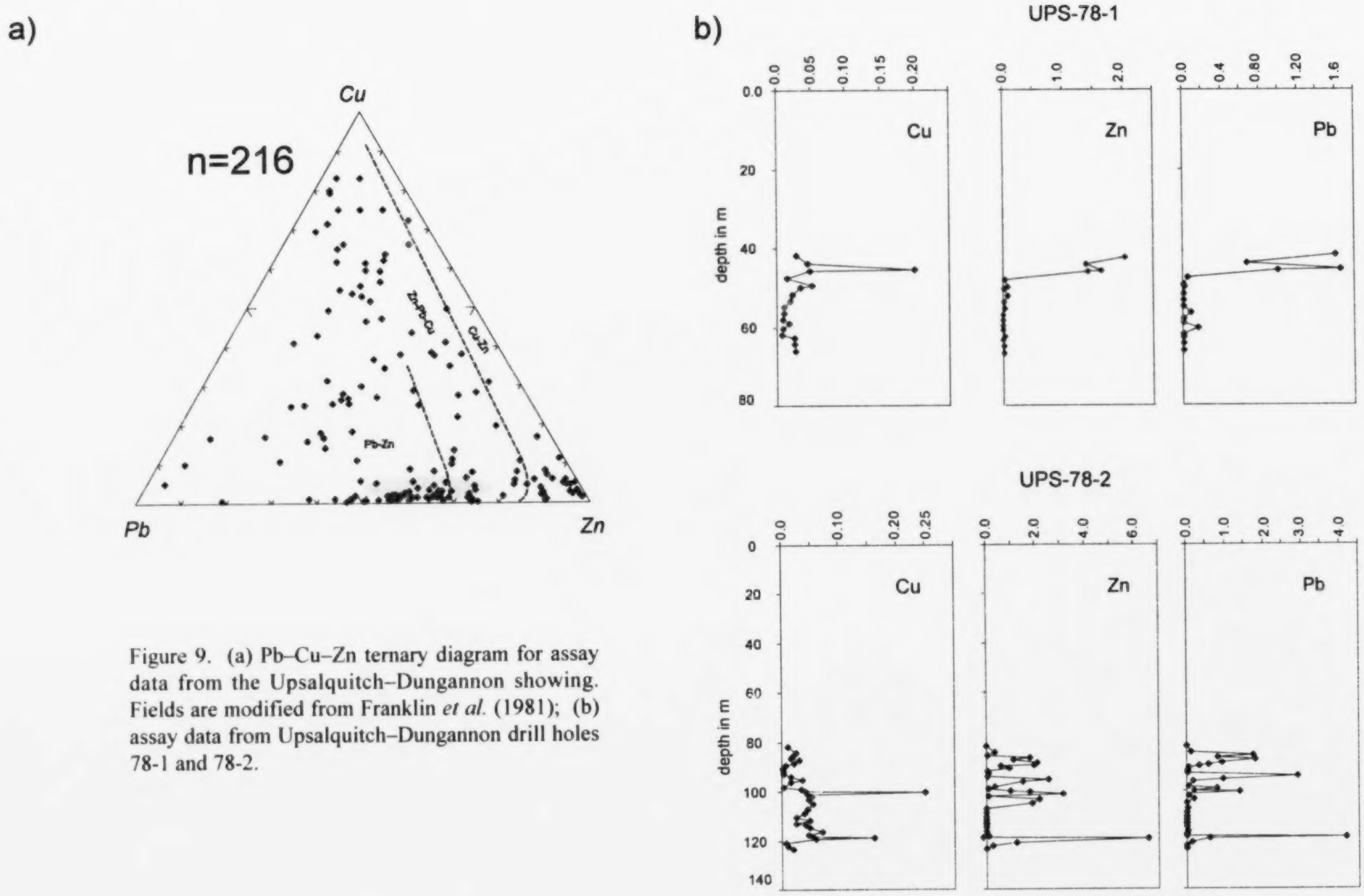

Figure 9. (a) Pb–Cu–Zn ternary diagram for assay data from the Upsalquitch–Dungannon showing. Fields are modified from Franklin *et al.* (1981); (b) assay data from Upsalquitch–Dungannon drill holes 78-1 and 78-2.

Unlike most base metal sulphide mineralization in the Bathurst Mining Camp, mineralization is dominated by pyrrhotite–chalcopyrite mineralization. Zn–Pb sulphides occur locally, and are associated with chloritically altered rocks. In general, mineralization in this part of the Bathurst Mining Camp can be classified into three types:

1) Proximal autochthonous stringer mineralization, dominated by pyrrhotite with Cu >> Pb + Zn, typical of the Devils Elbow and TV Tower sulphide bodies.
2) Stratiform massive sulphides dominated by pyrite with Zn + Pb > Cu. The pyrrhotite content in these bodies is minor to nil. This type of mineralization is typical of the Mount Fronsac and Mount Fronsac North deposits.
3) Intensely chloritic rocks containing richly disseminated pyrite and occurring close to the Nepisiguit Falls–Flat Landing Brook contact, typical of the TV Tower East #1, #2, and #3 occurrences. These are probably distal equivalents of type two mineralization.

Pyrrhotite- ± chalcopyrite mineralization, in the Upsalquitch–Dungannon zone is interpreted to represent originally disconformable stringer-type mineralization (Type 1 above), rather than pyrrhotite-rich stratiform mineralization. This interpretation is supported by the enrichment of Eu in discrete zones symmetrical with respect to the more intense sulphide mineralization. The depletion of Nb in these same zones is also suggestive of footwall alteration.

The timing of mineralization at the Upsalquitch–Dungannon occurrence is constrained by the intensely altered mafic dyke discussed above. The similarity in style of alteration in the porphyritic rocks and the dyke suggests that the dyke predates, or is at least synchronous, with mineralization. If, as suggested above, the dyke is a feeder to the Forty Mile Brook basalts of the Flat Landing Brook Formation, mineralization must be Flat Landing Brook age, i.e., younger than the Brunswick Horizon. However, if the dyke were tapped from a lower, less-evolved part of the Nepisiguit Falls magma chamber, Upsalquitch–Dungannon mineralization could be synchronous with the Brunswick Horizon. The latter hypothesis, although plausible, does not have a known analogue in the Bathurst Mining Camp.

Although the Upsalquitch–Dungannon sulphide occurrence is not significant in terms of tonnage or grade, it represents proximal autochthonous pyrrhotite–chalcopyrite stringer mineralization within the Nepisiguit Falls Formation. The proximity of this style of mineralization to sedimentary rocks of the Nepisiguit Falls Formation suggests the potential for discovery of a Brunswick–type deposit in this area.

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REFERENCES

Adair, R.N. 1992. Stratigraphy, structure and geochemistry of the Halfmile Lake massive-sulfide deposit, New Brunswick. Exploration and Mining Geology **1**: 151–166.

BELLAND, M. 1992. The birth of the Bathurst Mining Camp: A development history of the Austin Brook iron mine and the No. 6 base-metal deposit. New Brunswick Department of Natural Resources and Energy, Minerals Resources, Popular Geology Paper 92-1, p. 56.

CARON, A. and GOWER, S.J. 1995. Geology of the Devils Elbow Brook area (NTS 21 O/08e) Northumberland County New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 95-6a.

DE ROO, J.A. and VAN STAAL, C.R. 1994. Transpression and extensional collapse: Steep belts and flat belts in the Appalachian Central Mobile Belt, northern New Brunswick, Canada. Geological Society of America, Bulletin, **106**: 541–552.

FRANKLIN, J.M., LYDON, J.W. and SANGSTER, D.F. 1981. Volcanic-associated massive sulfide deposits. Economic Geology, 75th Anniversary Volume, pp. 485–627.

GALE, G.H., DABEK, L.B. and FEDIKOW, M.A.F. 1997. The application of rare earth element analyses in the exploration for volcanogenic massive sulfide type deposits. Exploration and Mining Geology **6**: 233–252.

GOWER, S.J. 1995. Preliminary petrology and lithogeochemistry of the Hartts Lake–Devils Elbow Brook area, Northumberland County, New Brunswick. *In* Current Research 1994. *Compiled and Edited by* S.A.A. Merlini. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Miscellaneous Report 18, pp. 1–24.

Gower, S.J. 1996. Geology, lithogeochemistry and mineral occurrences in the Portage Brook area, northwestern Bathurst Mining Camp, New Brunswick (NTS 21 O/07h, part of 21 O/10a). *In* Current Research 1995. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 96-1, pp. 13–43.

GOWER, S.J. and MCCUTCHEON, S.R. 1995. Hartts Lake–Murray Brook project (NTS 21 O/8e and f), Northumberland County, New Brunswick. *In* Geoscience Research 1994. *Compiled and Edited by* J.P. Langton. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Miscellaneous Report 15, pp. 1–13.

GRAF Jr., J.L. 1977. Rare earth elements as hydrothermal tracers during the formation of massive sulfide deposits in volcanic rocks. Economic Geology, **72**: 527–548.

GUMMER, P.K. 1977. Report of work on the Upsalquitch property for Dungannon Explorations Ltd. (NTS 21 O/8). New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division; Mineral Exploration Report of Work, Assessment File 472121.

GUMMER, P.K. 1979. Report of work for 32 mining claims of the Upsalquitch property for Dungannon Explorations Ltd. (NTS 21 O/8W). New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division; Mineral Exploration Report of Work, Assessment File 472373.

HUXHOLD, P. 1981a. Report of work on mining lease 1303, Upsalquitch property for Dungannon Explorations Ltd. (NTS 21 O/8W). New Brunswick Department of Natural Resources and Energy; Minerals Policy and Planning Division; Mineral Exploration Report of Work, Assessment File 472753.

HUXHOLD, P. 1981b. Report of work on mining lease 1297 for Dungannon Explorations Ltd. (NTS 21 O/8W). New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division; Mineral Exploration Report of Work, Assessment File 472762.

LANGTON, J.P. and MCCUTCHEON, S.R., 1993. Brunswick Project, NTS 21 P/5 west, 21 P/4 west, Gloucester County, New Brunswick. *In* Current Research. *Compiled and Edited by* S.A. Abbott. New Brunswick Department of Natural Resources and Energy, Mineral Resources, Information Circular 93-1, pp. 31–51.

LEITCH, C.H.B. and LENTZ, D.R. 1994. The Gresens approach to mass balance constraints of alteration systems: Methods, pitfalls and examples. *In* Alteration and alteration processes associated with ore-forming systems. *Edited by* D.R. Lentz. Geological Association of Canada, Short Course Notes 11, p. 467.

LENTZ, D. 1996. Trace-element systematics of felsic volcanic rocks associated with massive sulphide deposits in the Bathurst Mining Camp: Petrogenetic, tectonic and chemostratigraphic implications for VMS exploration. *In* Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration. *Edited by* D.A. Wyman. Geological Association of Canada, Short Course Notes 12, pp. 359–402.

LENTZ, D. and GOODFELLOW, W. 1992. Re-evaluation of the petro-chemistry of felsic volcanic and volcaniclastic rocks near the Brunswick No. 6 and 12 massive sulphide deposits, Bathurst Mining Camp, New Brunswick. *In* Current Research, Part E. Geological Survey of Canada, Paper 92-1E, pp. 343–350.

LENTZ, D. and GOODFELLOW, W. 1993. Petrology and mass-balance constraints on the origin of quartz- augen schist associated with the Brunswick massive sulfide deposits, Bathurst, New Brunswick. Economic Geology, **31**: 877–903.

LOUDEN, J.R. 1960. The origin of the porphyry and the porphyry-like rocks of Devils Elbow, New Brunswick unpublished Ph.D. Thesis, University of Toronto, 173 p.

MCCLENAGHAN, S. 2002. Gold in massive sulphide deposits, Bathurst Mining Camp: Form distribution and genesis. Unpublished MSc. thesis, University of Ottawa.

MCCUTCHEON, S.R. 1992. Base-metal deposits of the Bathurst–Newcastle District: Characteristics and depositional models. Exploration and Mining Geology, **1**: 105–119.

MCCUTCHEON, S.R., LUFF, W.M., and BOYLE, R.W. In press. The Bathurst Mining Camp, New Brunswick, Canada: History of discovery and evolution of geological models. *In* Massive Sulfide Deposits of the Bathurst Mining Camp, New Brunswick and Northern Maine. *Edited by* W.D. Goodfellow, S.R. McCutcheon, and J.M. Peter. Economic Geology Monograph 11, Economic Geology Publishing Company.

MCCUTCHEON, S.R., WALKER, J.A., and MCCLENAGHAN, S.H. 2001. The geologic setting of massive sulphide deposits in the Bathurst Mining Camp: A synthesis. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resources Report 2001-4, pp. 63–95.

MCCUTCHEON, S.R., LANGTON, J.P., VAN STAAL, C.R. and LENTZ, D.R. 1993. Stratigraphy, tectonic setting and massive sulphide deposits of the Bathurst Mining Camp, northern New Brunswick. *In* Guidebook to the Metallogeny of the Bathurst Camp. *Edited by* S.R. McCutcheon and D.R. Lentz. Trip #4, Bathurst '93, 3rd Annual Field Conference, Geological Society, Canadian Institute of Mining and Metallurgy, pp. 1–39.

MERSEREAU, T.G. 1999. Report on geochemical, line-cutting, geophysical and geological assessment report for the Tower Claim Group (NTS 21 O/8W). New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division; Mineral Exploration Report of Work, Assessment File 475189.

NAKAMURA, N. 1974. Determination of REE Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites. Geochemica Cosmochemica Acta, **38**: 757–775.

PEARCE, J.A., HARRIS, N.B.W. and TINDLE, A.G. 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. Journal of Petrology, **25**: 956–983.

ROLLINSON, H. 1995. Using geochemical data: evaluation, presentation and interpretation. Published by Longman Group UK Ltd. ISBN 0 582 06701 4, p. 352.

ROSE, D.G. and JOHNSON, S.C. 1990. New Brunswick computerized mineral occurrence database. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resources Report 3, p. 69.

THOMAS, M.D., WALKER, J.A., KEATING, P., SHIVES, R., KISS, F. and GOODFELLOW, W.D. 2000. Geophysical atlas of massive sulphide signatures, Bathurst Mining Camp, New Brunswick. Geological Survey of Canada, Open File 3887 / New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-4, p. 105.

VAN STAAL, C.R. 1994. Brunswick subduction complex in the Canadian Appalachians: record of the Late Ordovician to Late Silurian collision between Laurentia and the Gander margin of Avalon. Tectonics, **13**: 946–962.

VAN STAAL, C.R. and FYFFE, L.R. 1991. Dunnage and Gander zones, New Brunswick: Canadian Appalachian Region. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Geoscience Report 91-2, 39 p.

VAN STAAL, C.R. and SULLIVAN, R.W. 1992. Significance of U–Pb zircon dating of silicic volcanic rocks associated with the Brunswick-type massive sulphide deposits of the Tetagouche Group. Geological Association of Canada/ Mineralogical Association of Canada, Joint Annual Meeting, Abstracts Volume 17, p. A112.

VAN STAAL, C.R., WINCHESTER, J.A. and BÉDARD, J.H. 1991. Geochemical variations in Middle Ordovician volcanic rocks of the northern Miramichi Highlands and their tectonic significance. Canadian Journal of Earth Sciences, **28**: 1031–1049.

VAN STAAL, C.R., WILSON, R.A., ROGERS, N., FYFFE, L.R., GOWER, S.J., LANGTON, J.P., MCCUTCHEON, S.R. and Walker, J.A. 2002. Geology, Bathurst Mining Camp and surrounding areas, New Brunswick. Geological Survey of Canada, Open File 4182, Scale 1:100 000.

VAN STAAL, C.R., WILSON, R.A., ROGERS, N., FYFFE, L.R., LANGTON, J.P., MCCUTCHEON, S.R., MCNICOLL, V. and RAVENHURST, C.E. In press. Geology and tectonic history of the Bathurst Supergroup, Bathurst Mining Camp and its relationship to coeval rocks in southwestern New Brunswick and adjacent Maine – a synthesis. *In* Massive Sulfide Deposits of the Bathurst Mining Camp, New Brunswick and Northern Maine. *Edited by* W.D. Goodfellow, S.R. McCutcheon, and J.M. Peter. Economic Geology Monograph 11, Economic Geology Publishing Company.

VON GUTTENBERG, R. 1979. Report of work on the Upsalquitch property, for Dungannon Explorations Limited (NTS 21 O/8W). New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division; Mineral Exploration Report of Work, Assessment File 472451.

VON GUTTENBERG, R. 1981a. Report of work on mining License No. 1297, for Dungannon Explorations Limited (NTS 21 O/8W). New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division; Mineral Exploration Report of Work, Assessment File 472655.

VON GUTTENBERG, R. 1981b. Report of work on mining License No. 1297, for Dungannon Explorations Limited (NS 21 O/8W). New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division; Mineral Exploration Report of Work, Assessment File 472683.

WALKER, J.A. 1997. Geology of the Devils Elbow copper deposit (NTS 21O/08W), Bathurst Mining Camp, New Brunswick. *In* Current Research, 1996. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resources Report 97-4, pp. 247–271.

WALKER, J.A. and GRAVES, G. In preparation. The Mount Fronsac North VMS deposit: a recent discovery in the Bathurst Mining Camp, New Brunswick. Exploration and Mining Geology.

WILSON, R.A., VAN STAAL, C.R., MCCUTCHEON, S.R. and FYFFE, L.R. 1998. Revised stratigraphic nomenclature for the Bathurst Mining Camp, northern New Brunswick. *In* Abstracts, 1998: 23rd Annual Review of Activities. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 98-3, pp. 59–60.

WINCHESTER, J.A. and FLOYD, P.A. 1977. Geochemical discrimination of different magma series and their differentiation products using immobile elements. Chemical Geology, **20**: 325–343.

STRUCTURAL GEOLOGY OF THE ALBERT MINES–TAYLOR VILLAGE AREA, SOUTHEASTERN NEW BRUNSWICK †

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WILSON, P. 2002. Structural geology of the Albert Mines–Taylor Village area, southeastern New Brunswick. *In* Current Research, 2001. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division; Mineral Resource Report 2002-4, pp. 129–153.

Current onshore petroleum exploration in southeast New Brunswick is focussing on an area straddling the Petitcodiac River in the vicinity of Albert Mines in the west and Taylor Village in the east. This area is structurally complex and has been affected by a number of fault sets with multiple periods of movement. A knowledge of timing of initiation, timing of reactivation and sense of the various phases of movement is clearly critical for the advancement of exploration efforts. Detailed field observations, reinterpretations of seismic reflection profiles, and a review of published maps have been integrated with the aim of elucidating the structural geology of this area. The study mainly concentrates on rocks of the Lower Carboniferous (Tournaisian) Albert and Weldon Formations of the Horton Group.

Recent interpretations of the tectonic evolution of the Moncton Subbasin have emphasized the role of dextral pull-apart on northeast-trending faults followed by dextral transpression and basin inversion. However, detailed field observations and map evidence reveal that some northeast-trending faults show evidence for late sinistral movements, especially in the south of the area. Thus, source and reservoir rocks may exhibit net sinistral offsets. Reinterpretation of seismic profiles coupled with field evidence reveals the importance of both high-angle and low-angle faults. Field observations indicate that different rock types in the area respond in very different ways to deformation and, therefore, fault zone characteristics show considerable spatial variation. Microstructural observations indicate that faults are likely to be sealed at levels below the water zone.

L'exploration pétrolière à terre courante sans le Sud-Est du Nouveau-Brunswick est axée sur un secteur chevauchant la rivière Petitcodiac à proximité d'Albert Mines dans l'ouest et de Taylor Village dans l'est. Ce secteur constitue une région structuralement complexe qui a été affectée par un certain nombre de systèmes de failles ayant comporté plusieurs périodes de mouvement. Il est manifestement crucial qu'on connaisse le moment de l'amorçage de ces mouvements et le moment de leur reprise et qu'on comprenne les diverses phases de mouvement pour faire avancer les travaux d'exploration. On a intégré des observations détaillées sur le terrain, des réinterprétations des profils de réflexion sismique et une révision des cartes publiées dans le but de clarifier la géologie structurale du secteur. L'étude se concentre principalement sur les roches du Carbonifère inférieur (Tournaisien) des Formations d'Albert et de Weldon du groupe de Horton.

Des interprétations récentes de l'évolution tectonique du sousbassin de Moncton ont mis en évidence le rôle de l'extension dextre sur les failles orientées vers l'est qui a été suivie d'une transpression dextre et d'une inversion du bassin. Les observations détaillées sur le terrain et les attestations

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† New Brunswick Geological Surveys Branch ordinary budget.

cartographiques révèlent toutefois que certaines failles orientées vers le nor-dest présentent des signes de mouvements senestres tardifs, spécialement dans le sud du secteur. Les roches sources et les roches réservoirs peuvent ainsi présenter des décalages senestres nets. La réinterprétation des profils sismiques, jumelée aux indices sur le terrain, révèle l'importance à la fois des failles redressées et des failles à faible pendage. Les observations sur le terrain signalent que les différents types de roches présents dans le secteur réagissent de façons très différentes à la déformation et qu'en conséquence, les caractéristiques des zones faillées présentent une variation spatiale considérable. Les observations microstructurales permettent de supposer que les failles sont probablement obturées à des niveaux situés audessous de la zone aquifère.

INTRODUCTION

The Moncton Subbasin is a substructure of the Upper Palaeozoic Maritimes Basin, a post-Acadian successor basin that underlies much of the Maritime Provinces and Gulf of St. Lawrence. A regional map of the Maritimes Basin in southeast New Brunswick is shown in Figure 1. Recent on-shore hydrocarbon exploration efforts in the Moncton Subbasin have focussed on an area straddling the Petitcodiac River from Albert Mines in the west to Taylor Village in the east (Figure 2). This area is structurally complex and is cut by numerous faults. Northeast-trending faults provide the main structural control. A knowledge of timing of initiation, timing of reactivation and sense of movement of the various fault sets is critical if attempts to exploit oil and gas resources from the region are to be realized. Five sections in the area were studied. They are shown in Figure 2 and include the Peck Creek, Frederick Brook, Boudreau Village, Belliveau Village and Taylor Village sections.

The specific aims of this project are to gather new structural and microstructural observations and use previously published maps and seismic data to: (1) establish a relative chronology for episodes of fault movement and fault reactivations, (2) provide an interpretation of fault mechanisms in the area, and (3) outline the implications these have for regional tectonics and petroleum exploration in the area.

ACCESS AND PHYSIOGRAPHY

To the east of the Petitcodiac River, the Boudreau Village, Belliveau Village and Taylor Village sections are exposed along the banks of the tidal Petitcodiac and Memramcook rivers. Access is provided by many secondary paved highways. Exposure is poor away from the river sections. To the west of the Petitcodiac River, the Frederick Brook and Peck Creek sections are in hilly and forested terrain. Access is generally fair via local paved roads and gravel forest roads. Exposure is poor apart from some good outcrops along streams.

STRATIGRAPHY

The stratigraphy of the Moncton Subbasin has been described and discussed in some detail (Bell 1929; Gussow 1953; Greiner 1962, 1974; Macauley *et al.* 1984; Carter and Pickerill 1985a, 1985b, 1985c; Macauley and Ball 1985; St. Peter 1992, 1993; van de Poll 1995). In this report the stratigraphy of St. Peter (1992) and St. Peter and Johnson (personal communication, 2002) will be used. Their stratigraphy is summarized in Table 1 and the rock units important to this study are briefly described below. The study mainly concerns the Upper Carboniferous (Tournaisian) Albert and Weldon formations of the Horton Group.

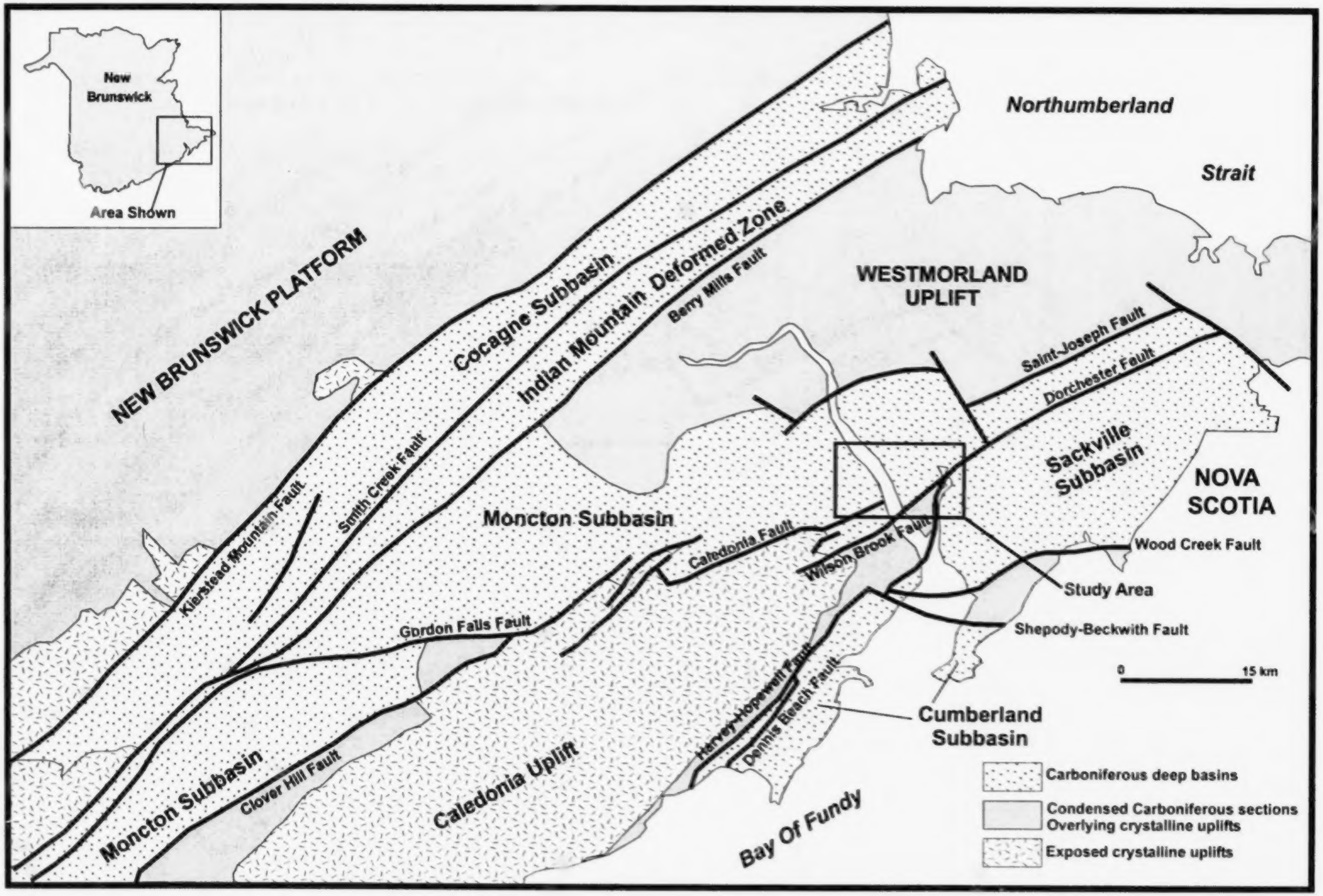


Figure 1. Regional map of the Maritimes Basin and intervening uplifts, showing the major faults. Redrawn after St. Peter (2001a).

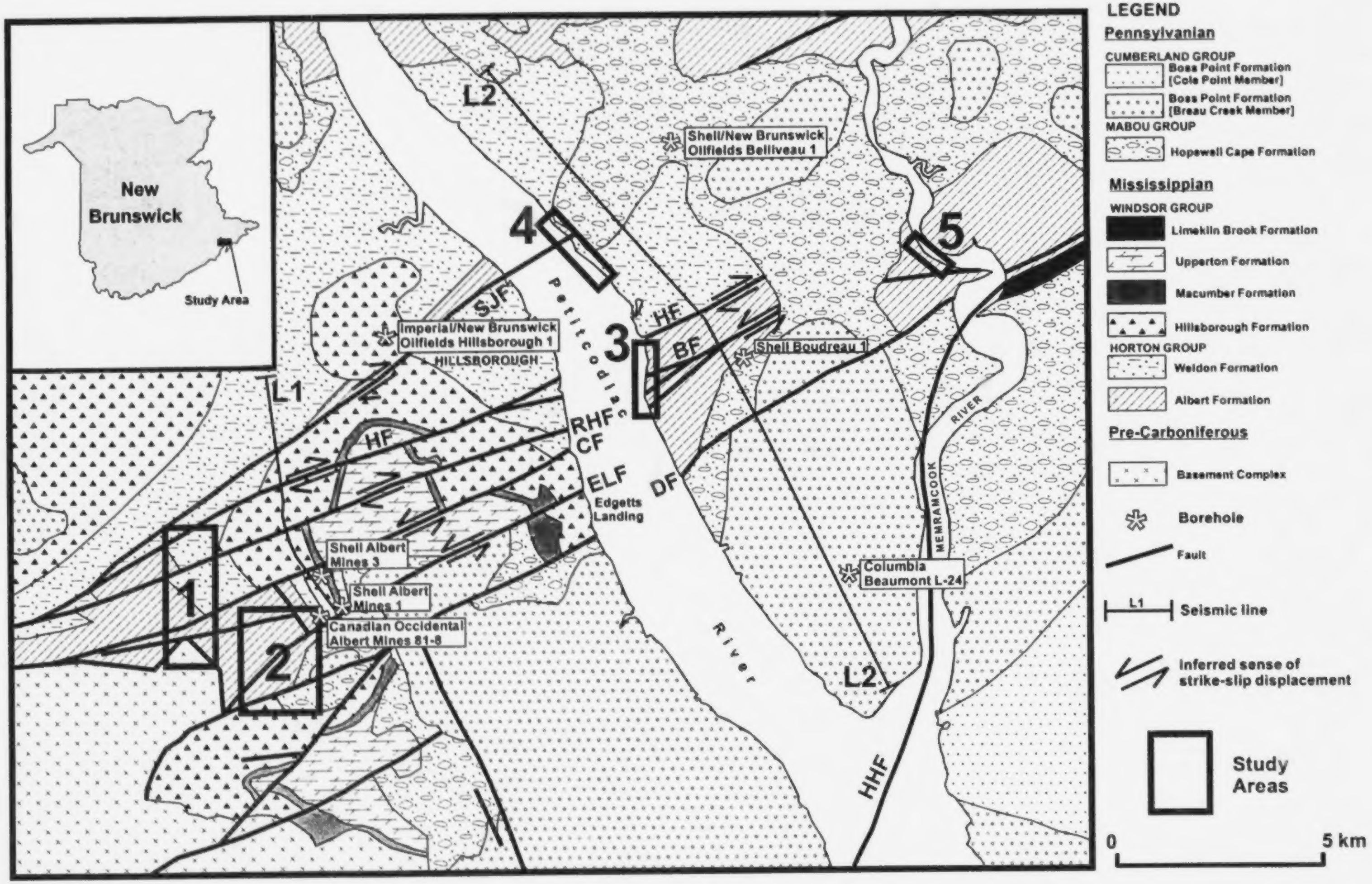
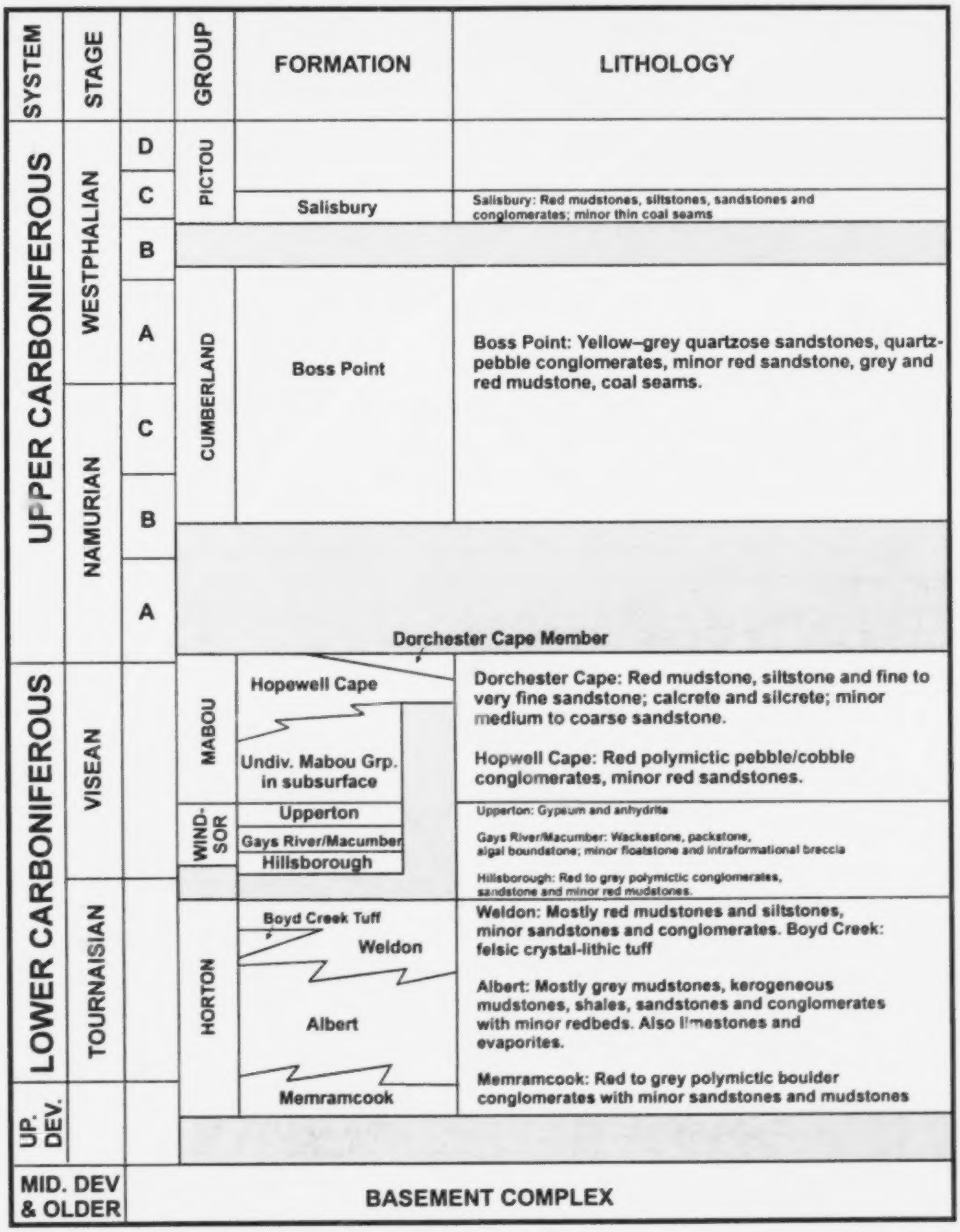


Figure 2. Geological map of the study area. Study areas are: **1** – Peck Creek (Figure 4); **2** – Frederick Brook (Figure 4); **3** – Boudreau Village; **4** – Belliveau Village and **5** – Taylor Village. Abbreviations: **SJF** – Saint-Joseph Fault; **HF** – Hillsborough Fault; **BF** – Boudreau Fault; **RHF** – Round Hill Fault; **CF** – Caledonia Fault; **ELF** – Edgetts Landing Fault; **DF** – Dorchester Fault; **HHF** – Harvey–Hopewell Fault. **L1** – seismic lineAT4-1947; **L2** – seismic line AT4-1949. Modified after St. Peter and Johnson (1997).

Table 1. Table of Formations for the Southeastern Moncton Subbasin



SYSTEM	STAGE		GROUP	FORMATION	LITHOLOGY
UPPER CARBONIFEROUS	WESTPHALIAN	D	PICTOU		
		C		Salisbury	Salisbury: Red mudstones, siltstones, sandstones and conglomerates; minor thin coal seams
		B			
		A	CUMBERLAND	Boss Point	Boss Point: Yellow–grey quartzose sandstones, quartz-pebble conglomerates, minor red sandstone, grey and red mudstone, coal seams.
	NAMURIAN	C			
		B			
		A		Dorchester Cape Member	
LOWER CARBONIFEROUS	VISEAN		MABOU	Hopewell Cape Undiv. Mabou Grp. in subsurface	Dorchester Cape: Red mudstone, siltstone and fine to very fine sandstone; calcrete and silcrete; minor medium to coarse sandstone. Hopwell Cape: Red polymictic pebble/cobble conglomerates, minor red sandstones.
			WIND-SOR	Upperton Gays River/Macumber Hillsborough	Upperton: Gypsum and anhydrite Gays River/Macumber: Wackestone, packstone, algal boundstone; minor floatstone and intraformational breccia Hillsborough: Red to grey polymictic conglomerates, sandstone and minor red mudstones.
	TOURNAISIAN		HORTON	Boyd Creek Tuff Weldon Albert Memramcook	Weldon: Mostly red mudstones and siltstones, minor sandstones and conglomerates. Boyd Creek: felsic crystal-lithic tuff Albert: Mostly grey mudstones, kerogeneous mudstones, shales, sandstones and conglomerates with minor redbeds. Also limestones and evaporites. Memramcook: Red to grey polymictic boulder conglomerates with minor sandstones and mudstones
UP. DEV.					
MID. DEV & OLDER	BASEMENT COMPLEX				

Redrawn after St. Peter (2001a).

Basement complex

The basement complex consists largely of metasediments, metavolcanics and igneous rocks of Proterozoic to Middle Devonian age. Basement rocks in southern New Brunswick are assigned to the Avalon Zone of the Appalachian orogen (Williams 1979). Recently, workers have subdivided the Avalon Zone into several terranes (e.g., Barr and White 1996 and references therein).

Horton Group

The Horton Group is the basal stratigraphic group of the Moncton Subbasin. It consists of the conformable Memramcook, Albert and Weldon formations.

The Memramcook Formation consists of purple–red polymictic conglomerates, arkosic sandstones and red mudstones. It is thought to be late Devonian in age because it is overlain by the earliest Carboniferous Albert Formation and because it contains late Devonian miospores in the type section at Stony Creek (Carr 1968).

The Early to Middle Tournaisian Albert Formation is important because it contains the source rocks for hydrocarbon accumulations in the study area. The Albert Formation consists of five members that have complex interdigitating relationships (e.g., Greiner 1974; Macauley *et al.* 1984; Carter and Pickerill 1985a, 1985b, 1985c; van de Poll 1995). The distal basin-centre facies comprise the Dawson Settlement, Frederick Brook, Hiram Brook and Gautreau members. The Dawson Settlement Member consists of mainly coarse to fine sandstones with intercalations of shale; the Frederick Brook Member consists of kerogeneous shale and minor sandstone; the Hiram Brook Member consists of kerogeneous and calcareous siltstones, shales and sandstones; and the Gautreau Member (Carter and Pickerill 1985b) comprises evaporites and shales thought to represent a salt-flat facies deposited during the drying up of lake Albert (e.g., van de Poll 1995), and is laterally equivalent to the Hiram Brook Member. The mainly conglomeratic Round Hill Member (Macauley *et al.* 1984; Carter and Pickerill 1985b) is thought to represent the near-source, proximal alluvial-fan facies equivalent of the distal basin facies (Carter and Pickerill 1985b; van de Poll 1995).

The Late Tournaisian Weldon Formation is the uppermost unit in the Horton Group (St. Peter 1992, 1993; but *cf.* Gussow 1953; Carter and Pickerill 1985b). It consists of red mudstones, siltstones and shales with minor conglomerates and limestone intercalations.

Windsor Group

The dominantly marine, Viséan-age Windsor Group is separated from underlying Horton Group rocks by a major unconformity. The group comprises the basal continental clastics of the Hillsborough Formation overlain by marine limestones of the Gays River and Macumber formations. The limestone units are conformably succeeded by anhydrite and gypsum of the Upperton Formation. In the western Moncton Subbasin and the Sackville Subbasin (Figure 1), the Upperton Formation is overlain by thick rock salt units (Cassidy Lake and Clover Hill formations). The rock salt is succeeded by carbonates, sulphates and both terrestrial and marine clastics of the Limekiln Brook Formation in the Sackville Subbasin (Figure 2). The marine units were deposited during the incursion of the Windsor sea into the Moncton Subbasin in Viséan times (e.g., van de Poll 1995). The Windsor Group is overlain by the Mabou Group. The contact is partly conformable, but locally unconformable (McCutcheon 1981).

Mabou Group

In the study area, the Late Viséan to Namurian A Mabou Group consists of polymictic red conglomerates and minor red sandstones of the Hopewell Cape Formation, which lies with pronounced angular unconformity on the Windsor and Horton beds. The conglomerates contain clasts derived from basement lithologies. The Hopewell Cape Formation is locally observed to be impregnated with bitumen. The Mabou Group is separated from overlying Cumberland Group rocks by a major unconformity.

Cumberland and Pictou groups

In the study area, the Cumberland Group consists of the yellow–grey sandstones, microconglomerates, quartz-pebble conglomerates and thin coal seams of the Boss Point Formation. The Boss Point is of Namurian B to Westphalian A age. The Cumberland Group in southeastern New Brunswick is paraconformably overlain by the Pictou Group. Fluvial strata of the Upper Carboniferous Pictou Group are exposed to the east, north and west of the study area (Gussow 1953).

SECTIONS STUDIED

Stereoplots of field observations from the study area are shown in Figure 3.

Peck Creek section

The section along Peck Creek (Figure 2, area 1; Figure 4) comprises Albert and Weldon formations in blocks bounded to the north and south by northeast-trending regional faults (Figure 4). These blocks are tilted to the east as evidenced by the presence of Hillsborough Formation to the east and Albert Formation to the west.

Stereoplots of structural data from Peck Creek (Figure 3a) show a clockwise rotation of bedding towards the major fault (Hillsborough Fault?) at locality 6 (see Figure 4), providing evidence for dextral movement on this fault. Exposures of Weldon Formation red mudstones at this locality show that the intensity of deformation increases towards the fault trace. Early macroscopic folding is transected by a local fault-parallel fracture cleavage carrying a subhorizontal slickenline lineation. The local fracture cleavage swings around in a clockwise sense as the fault to the north is approached, providing further evidence for dextral movement. Kink bands, which overprint the fracture cleavage, show reverse, south-side-up sense of movement. The fracture cleavage is observed to be crenulated into a steep northeast-trending crenulation cleavage. Sheared Weldon Formation mudrocks close to the Round Hill Fault at locality 5 (see Figure 4) contain Riedel shears and centimetre-scale drag folds that provide evidence for dextral movement on this fault.

Field observations and stereoplot analysis indicate that folds in the southern part of the section are upright and plunge 10–30° to the northwest. Mesoscopic folds in the northern part of the section are observed to be upright and plunge approximately 80° to the east (e.g., at locality 4, see Figure 4; Figure 5a).

At locality 1 (Figure 4), Albert Formation polymictic conglomerate is juxtaposed against Proterozoic basement volcanics along an east-trending fault zone. Thin sections from the fault zone show a complex history of brittle–ductile deformation and fault zone development (Figure 5b). Samples from the main

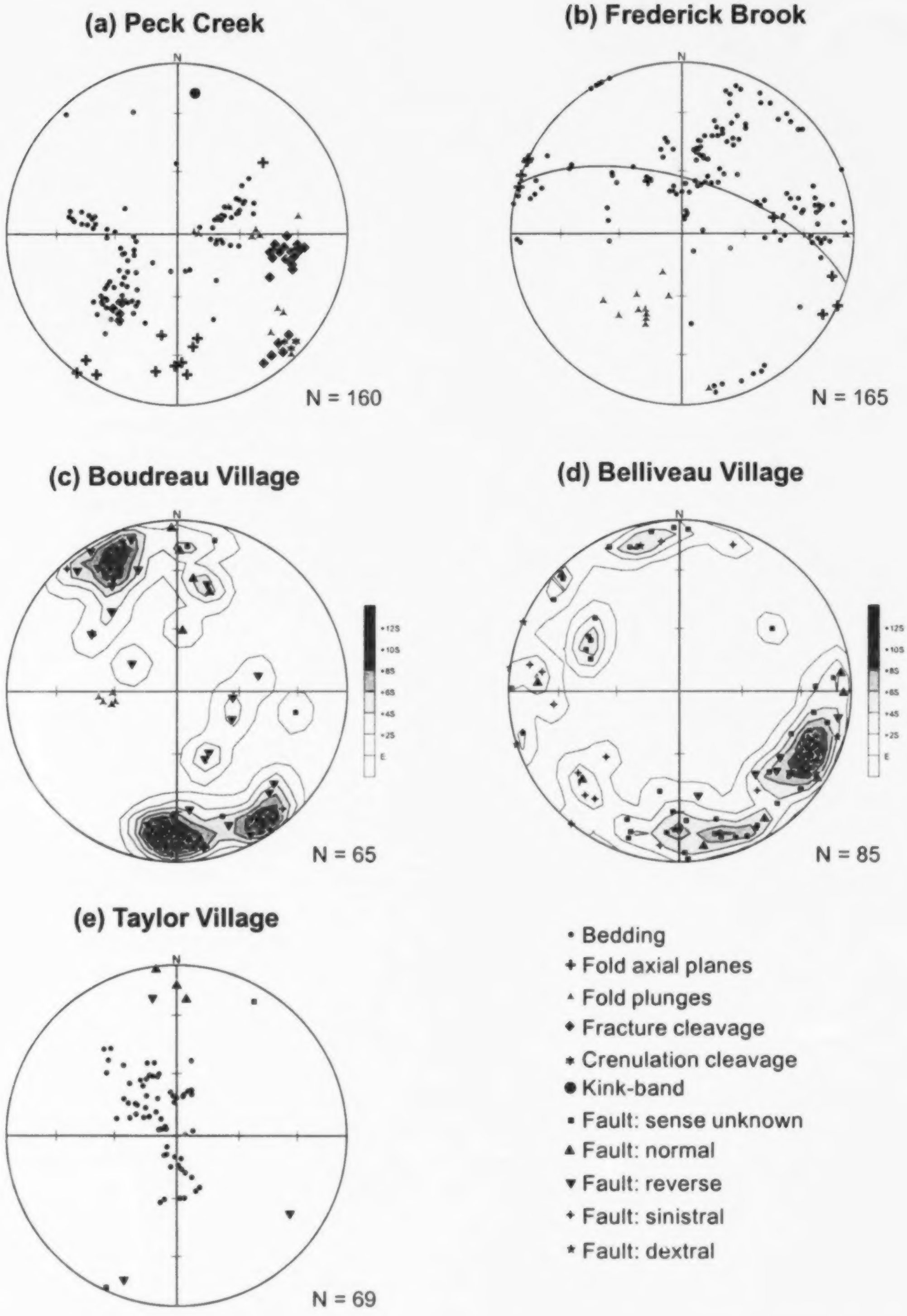


Figure 3. Stereoplots of field observations from the study area. (a) Peck Creek. (b) Frederick Brook. (c) Fault orientations from the Boudreau Village section. (d) Fault orientations from the Belliveau Village section. (e) Fault and bedding orientations from the Taylor Village section.

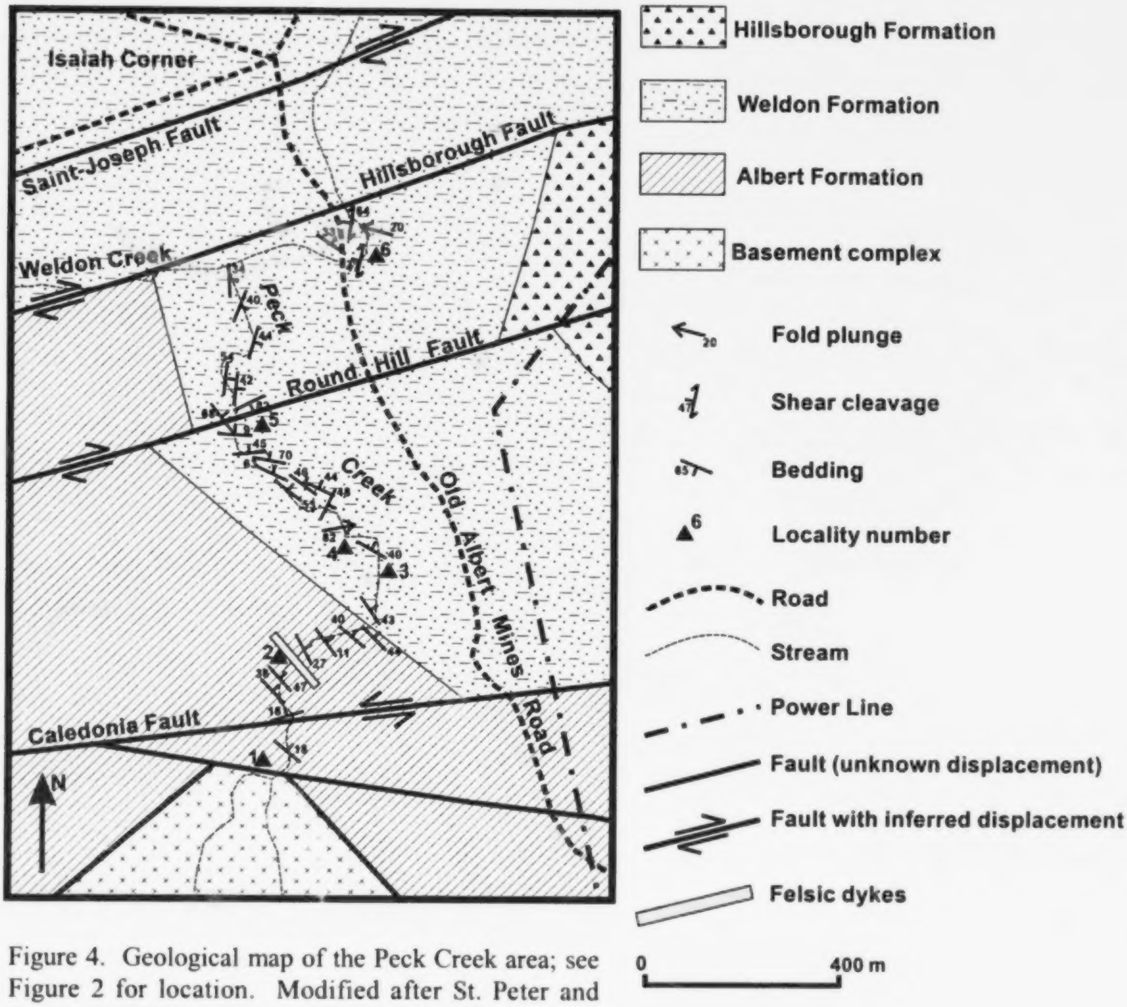


Figure 4. Geological map of the Peck Creek area; see Figure 2 for location. Modified after St. Peter and Johnson (1997).

fault zone show brecciated fragments of basement greenschist and Albert Formation conglomerates re-brecciated and healed with calcite veins. There are numerous generations of calcite veins with older veins generally fine grained and younger veins coarser, exhibiting blocky textures and little evidence of internal strain. Quartz-rich clasts derived from Albert conglomerate in these fault rocks generally show evidence for severe internal deformation (Figure 5b), exhibiting undulose and patchy extinction, neoblast formation and protomylonitic microstructures.

At locality 2 (Figure 4), deformation is associated with approximately northwest-trending felsic dykes. The age of these dykes is not known, but they may be related to the Boyd Creek Tuff, a felsic tuff that occurs within the Weldon Formation. In this case, the dykes would be Late Tournaisian in age (St. Peter 1992). Samples from the deformed dykes provide evidence for a complex deformation history with formation of calcite veins playing an important role (Figure 5c). The felsic dykes are composed of mostly quartz and feldspar and, in general, show evidence of severe ductile deformation (Figure 5c), with mylonitic textures observed in some quartz-rich fragments. In some samples, the dyke material is brecciated and quartz-mylonitic clasts and elongated and attenuated carbonate clasts are common. Fragments of deformed

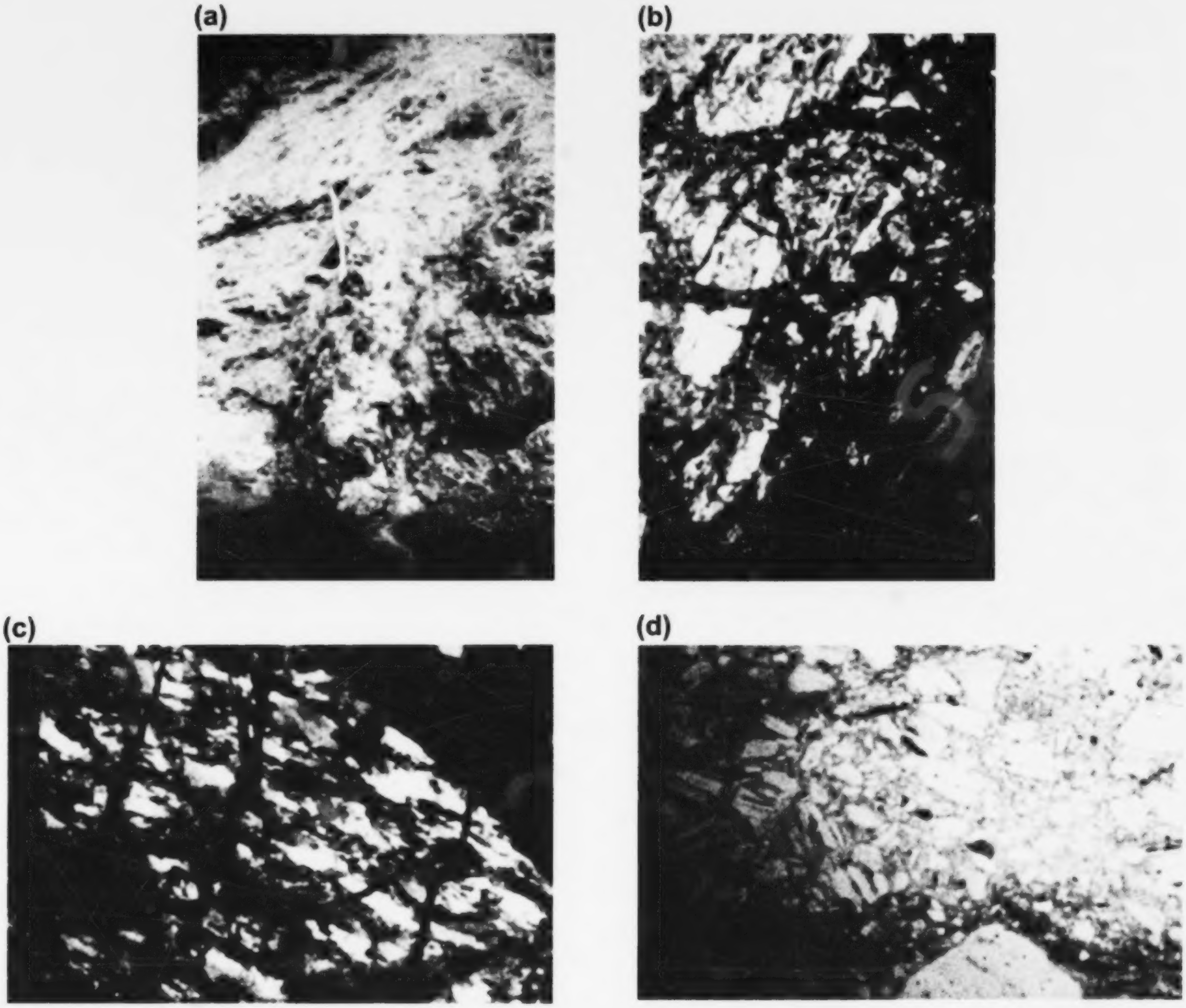


Figure 5. Field observations and microstructures from the Peck Creek section. (a) Steeply eastward-plunging mesoscopic fold at locality 4 (see Figure 4 for location). Fallen branch near centre is approximately 1 m long. (b) Fault rock from locality 1 (see Figure 4 for location). Note deformed quartz clasts from Albert Formation polymictic conglomerate cut by bands of cataclasite and carbonate veins. Crossed polars, field of view approximately 9 mm across. (c) Deformed felsic dyke from locality 2 (see Figure 4 for location). A quartz fragment showing protomylonitic texture is cut by fine-grained carbonate veins. Crossed polars, field of view approximately 2 mm across. (d) Brecciated clast in deformed Albert Formation conglomerate at locality 2 (see Figure 4 for location). Plane polarized light, field of view approximately 9 mm across.

quartz–calcite veins are commonly found, indicating that veins did not act passively during deformation. The dykes are cut by several generations of calcite veins, with older veins being fine grained and younger veins coarser. Veins are generally blocky rather than fibrous. Samples of Albert Formation conglomerates adjacent to the deformed dykes appear to be little deformed. However, some of the more elongate clasts in the conglomerate are brecciated (Figure 5d) and other clasts are fractured and healed with calcite veins. The conglomerates are generally matrix-supported; this would allow them to deform easily by particulate flow without any obvious deformation of the clasts. The conglomerates contain fewer veins than the dykes, perhaps because the conglomerates deformed without dilation and fracture formation.

Frederick Brook section

At Frederick Brook (Figure 2, area 2; Figure 6), Albert Formation rocks are bounded to the north and south by regional northeast-trending faults (the Caledonia and Taylor Village faults (St. Peter 1992, Figure 5) to the north and the Dorchester fault to the south) and to the east and west by northwest-trending faults.

A stereoplot of field observations from Frederick Brook is shown in Figure 3b. Poles to bedding plot on a great circle, which indicates that the area is dominated by one generation of upright cylindrical folds with the local fold plunge approximately 30° towards 200°. Mesoscopic folds in outcrop (e.g., at localities 2 and 3, Figure 6) have plunges roughly corresponding to this orientation. A generation of recumbent folds is also observed in this area (e.g., locality 4, Figure 6). The poles to the limbs of recumbent folds plot on the great circle, suggesting that the recumbent folding is early (i.e., F_1) and the main fold generation is later (F_2). Despite the pervasive folding in this area, no axial-planar cleavage was observed in outcrops except in the hinge of the small recumbent fold at locality 4.

On the south tributary of Frederick Brook at locality 1 (Figure 6), bedding in the Albert Formation is overturned against the Dorchester Fault to the south. This is consistent with a reverse-sense, north-side-up movement on the fault; it does not preclude the possibility of other episodes of movement. Where bedding is affected by fault drag, poles to bedding do not plot on the great circle that defines the main local fold trend, indicating that fault movement post-dates folding in the area. Regionally, this is supported by contrasting fold orientations between fault-bounded domains.

Along the northern part of Frederick Brook, Albert Formation shales are in contact with Albert Formation conglomerates across a northwest-trending fault (locality 6, Figure 6). Close to this fault, Albert Formation bedding is subvertical, and poles to bedding do not plot on the main fold trend. Again, this indicates that fault movement postdates folding. At locality 7 (Figure 6) the Hillsborough Formation of the Windsor Group contains small northeast-trending veins of solid bitumen (Albertite). At locality 5 (Figure 6), exposures of Hopewell Cape Formation conglomerate on the south side of the Old Albert Mines Road are saturated with bitumen. Therefore, hydrocarbon migration occurred after Mabou Group deposition, that is, during or after Namurian time.

Boudreau Village section

The Boudreau Village section (Figure 2, area 3) is the best exposed section of Albert Formation rocks in the study area. It is cut by three major faults (the Boudreau Fault, Round Hill Fault and Taylor Village Fault) and a large number of subsidiary faults. The Boudreau Fault is a regionally significant northeast-trending structure. A schematic cross section showing the faults and their inferred senses of displacement is shown in Figure 7.

A stereoplot of fault orientations from Boudreau Village is shown in Figure 3c. Three groups of fault orientations can be delineated, as follows:

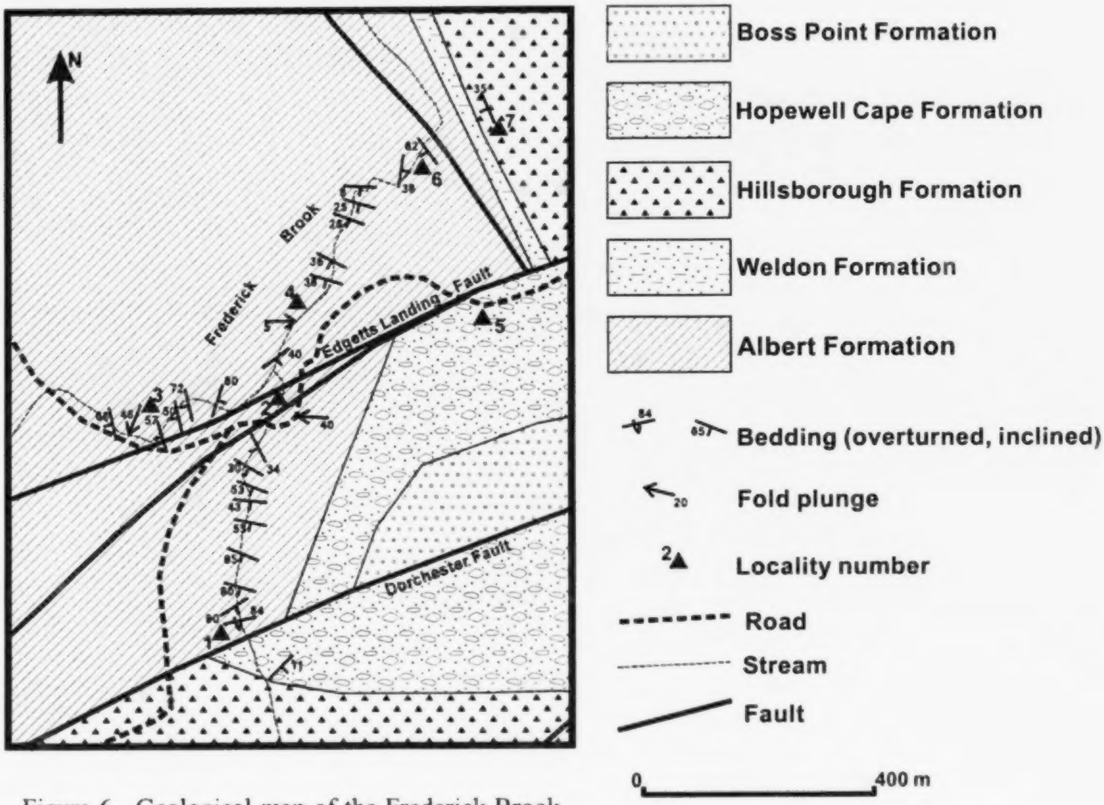


Figure 6. Geological map of the Frederick Brook area; see Figure 2 for location. Modified after St. Peter and Johnson (1997).

1. Low-angle faults with various trends. These are mostly thrust faults.
2. Steep northeast-trending faults. These are mostly high-angle reverse and sinistral faults, and:
3. Steep east-trending faults. These are mostly normal faults.

Cross-cutting relationships suggest that thrust faults are the earliest structures, high-angle reverse and sinistral faults formed later and normal faults later still.

The Boudreau Village section is divided into three domains characterized by distinctly different structural styles (Figure 7). In domain 1, red and grey mudstones, siltstones and minor sandstones dip approximately 50° to the west. The domain is cut by steep east- to northeast-trending faults, especially in the area close to the Boudreau Fault. Riedel shears and drag folds suggest that most of these faults are reverse faults (Figure 8a), though normal faults exist also. Immediately to the north of the Boudreau Fault, bedding is folded into a moderately westward-plunging anticline. If this anticline represents a drag fold, it is consistent with initial sinistral-south-side-down oblique movement on the Boudreau Fault.

In domain 2, bedding is near-vertical to slightly overturned and strikes east to northeast. In the north of the domain, drag folds, asymmetric folds (Figure 8b) and steps on slickensided surfaces suggest that the most recent fault movement is dominantly sinistral. Slickenlines have plunges in the range 10–40°. In

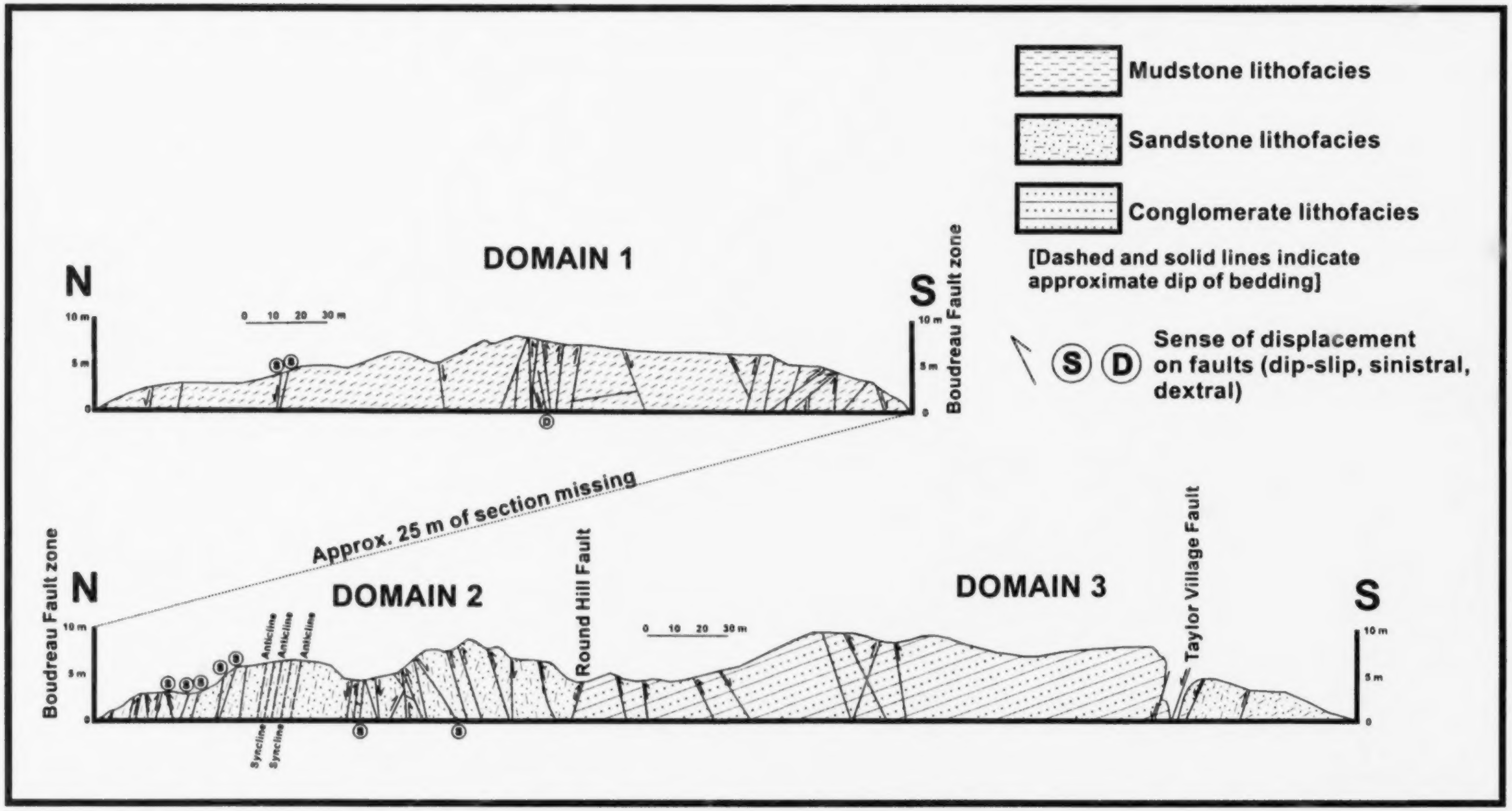


Figure 7. Schematic cross-section of the Boudreau Village section, showing the positions of faults and their inferred displacements.

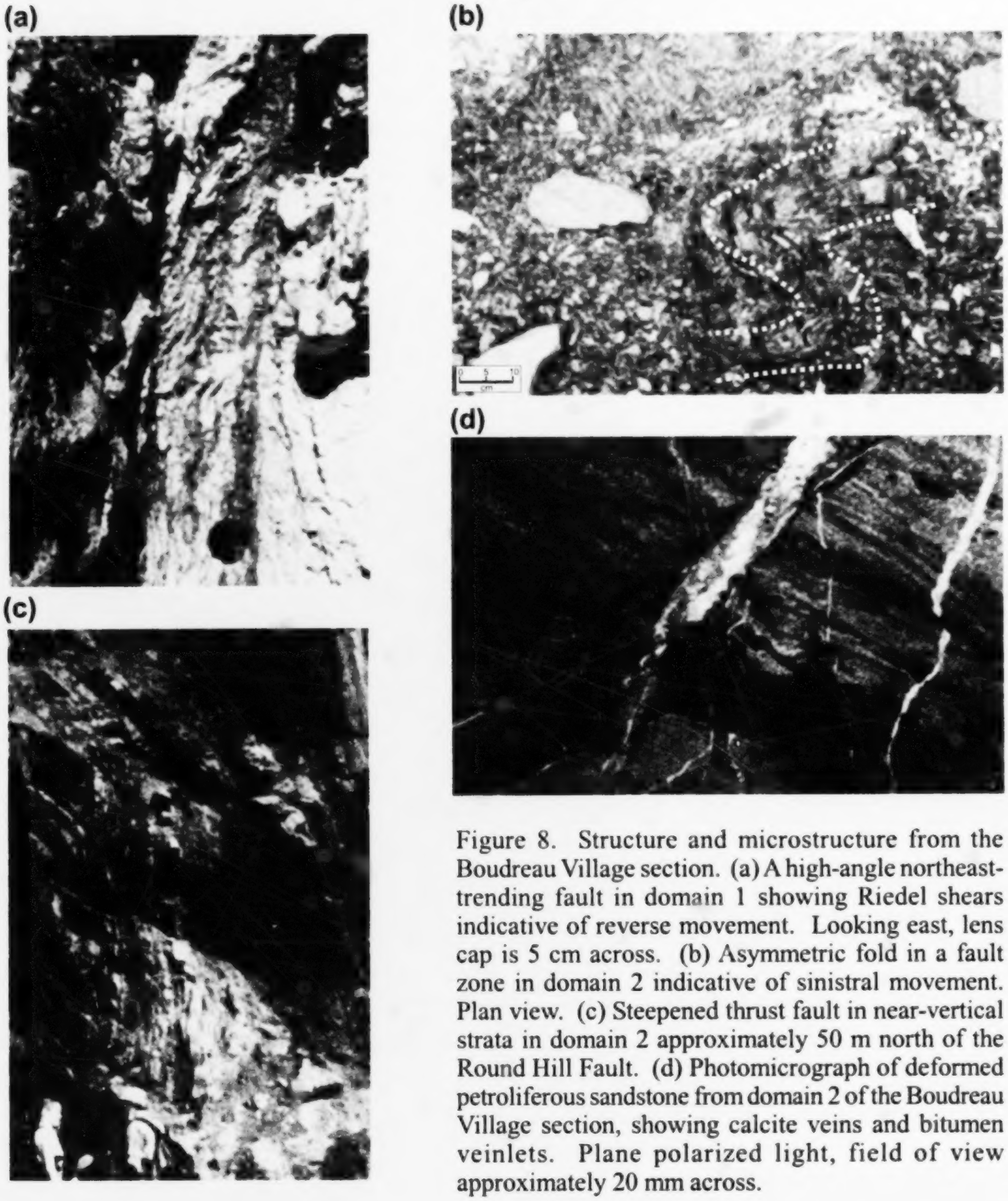


Figure 8. Structure and microstructure from the Boudreau Village section. (a) A high-angle northeast-trending fault in domain 1 showing Riedel shears indicative of reverse movement. Looking east, lens cap is 5 cm across. (b) Asymmetric fold in a fault zone in domain 2 indicative of sinistral movement. Plan view. (c) Steepened thrust fault in near-vertical strata in domain 2 approximately 50 m north of the Round Hill Fault. (d) Photomicrograph of deformed petroliferous sandstone from domain 2 of the Boudreau Village section, showing calcite veins and bitumen veinlets. Plane polarized light, field of view approximately 20 mm across.

the central part of the domain, upright, tight, steeply plunging folds with wavelengths of approximately 1 m and amplitudes of approximately 5 m are observed, indicating contraction across the domain. Axial planes to the folds are 20–30° clockwise of the main fault trend; if these folds are en-echelon folds related to shearing in the domain, they are consistent with sinistral movement. In the south of the domain, structure is dominated by reverse faults, including the domain-bounding Round Hill Fault. In this area early thrust faults, which have been steepened by later events, are also visible, notably approximately 50 m to the north of the Round Hill Fault (Figure 8c). Locally in domain 2, dextral-sense shears and kinks can be observed cutting across earlier fault zones at high angles. These are thought to mostly represent antithetic R′ shears associated with the larger sinistral fault zones. Observations from this domain that sinistral and reverse faults have similar orientations, that strike-slip faults occur near the Boudreau fault, that reverse faults occur farther away from the Boudreau Fault, that slickenline lineations are dominantly oblique, and that folds indicating contraction exist, are interpreted as indicating that domain 2 at Boudreau Village forms an asymmetric positive flower structure (Harding 1985; Woodcock and Fischer 1986; Woodcock and Schubert 1994). Therefore, sinistral and reverse movements are likely penecontemporaneous. Thus, domain 2 is believed to represent a sinistral transpression zone associated with the Boudreau Fault. Because deformation is highly distributed in domain 2, the domain will be referred to as the Boudreau deformation zone.

Microstructural analysis of deformed Albert Formation rocks from domain 2 shows that deformation was highly brittle. The rocks are heavily fractured and cut by calcite veins and bitumen veinlets (Figure 8d). Carbonate veins are approximately north-trending while bitumen veinlets are approximately east-trending. Small-scale displacements across bitumen veinlets are in most cases sinistral in sense. In the samples studied, carbonate veins cut bitumen veins, and therefore are later. Carbonate veins are up to 10 mm in width and show little evidence of internal strain.

In domain 3, to the south of the Round Hill Fault, the section is dominated by little-deformed gently north-dipping polymictic conglomerates. At the south end of domain 3, the conglomerates are juxtaposed against sandstones by the northeast-trending Taylor Village Fault. Drag-folds in sandstones immediately to the south of the Taylor Village Fault are consistent with normal-sense movement on the fault.

Belliveau Village section

The Belliveau Village section (Figure 2, locality 4) consists of Albert Formation shales to the northwest and Weldon Formation red mudstones and siltstones to the southeast. The formations are in contact along the Saint-Joseph Fault. Weldon Formation rocks are folded into a broad, open, kilometre-scale upright syncline that plunges gently to the southwest. A schematic cross-section is given in Figure 9.

A stereoplot of fault orientations from the Belliveau Village section is shown in Figure 3d. Three orientation groups can be delineated, as follows:

1. A small group of northwest-trending sinistral-sense faults, which are cut by other faults, and thus are thought to be early structures,
2. An approximately northeast-trending set dominated by reverse and dextral displacements, and,
3. A set trending approximately 080°, which are mostly of unknown displacement. By analogy to the Boudreau Village section, these may be mainly normal faults.

Cross-cutting relationships suggest that sinistral faults are earliest, reverse and dextral faults later, and normal faults later still.

On the wave-cut platform at the southeast end of the section, there are exposures of highly fractured and sheared Weldon Formation mudstones. Deformation intensity increases towards the southeast, suggesting there is a major fault in the unexposed interval between the southeast end of the Belliveau Village section and the north end of the Boudreau Village section. This would correspond to the Hillsborough Fault (St. Peter 1992, 1993; *cf.* St. Peter and Johnson 1997).

Immediately to the north of the Saint-Joseph Fault there is evidence of early tectonic activity. A steeply dipping, approximately east-trending bedding-parallel contact between redbeds (Weldon Formation?)

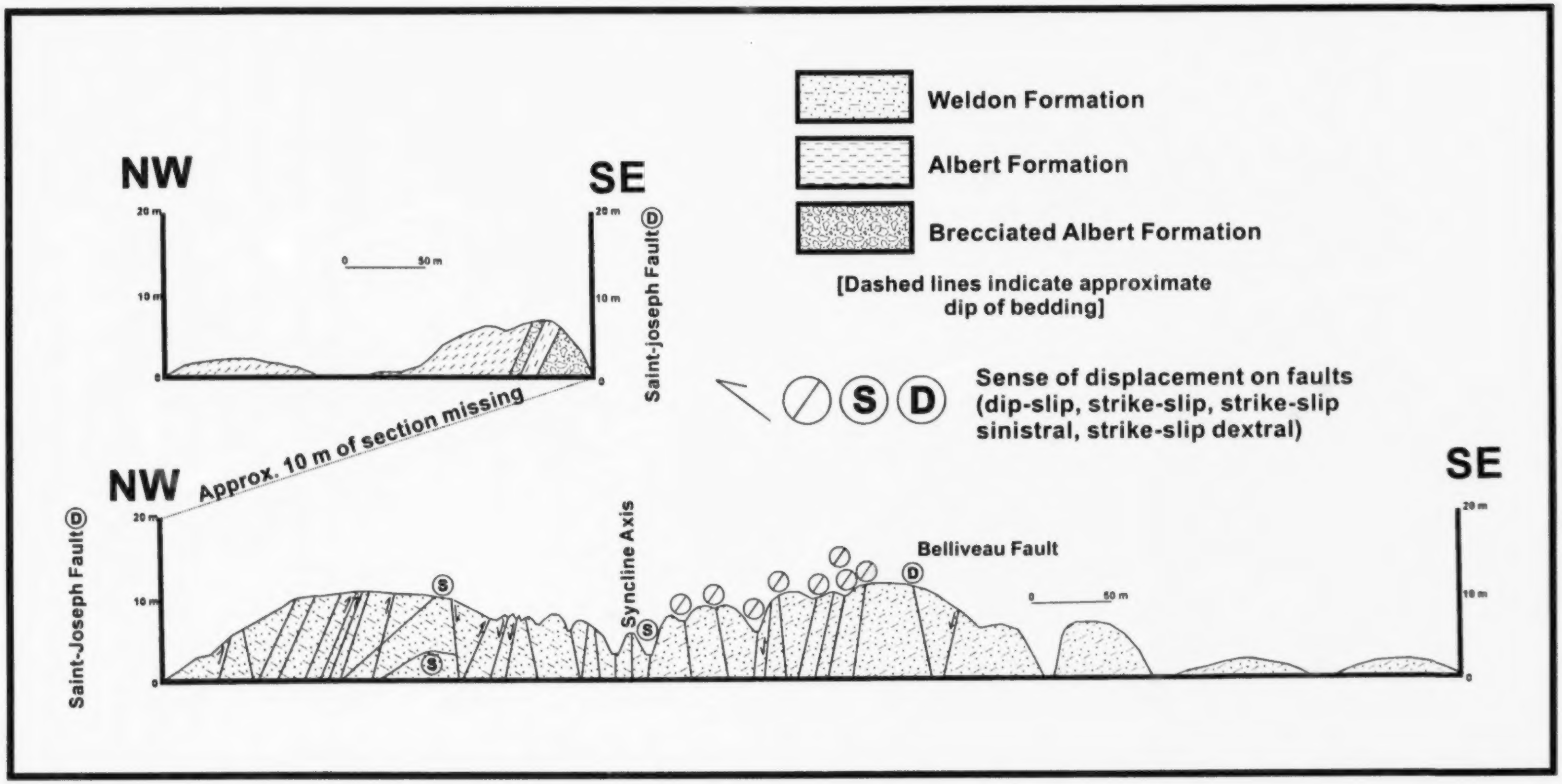

NW
SE
20 m
10 m
0
0
50 m
Saint-Joseph Fault D
Approx. 10 m of section missing
Weldon Formation
Albert Formation
Brecciated Albert Formation
[Dashed lines indicate approximate dip of bedding]
S
D
Sense of displacement on faults (dip-slip, strike-slip, strike-slip sinistral, strike-slip dextral)
Saint-Joseph Fault D
Syncline Axis
Belliveau Fault

Figure 9. Schematic cross-section of the Belliveau Village section, showing the positions of faults and their inferred displacements.

and grey Albert Formation rocks can be observed on the tidal platform. The contact is associated with parallel gouge and fault breccia zones, suggesting it is a tectonic contact. The sense of movement on this contact is unknown, but the bedding-parallel nature of the boundary is consistent with thrust movement. The contact is cut by the Saint-Joseph Fault and thus represents an early structure. Microstructural analysis reveals that the fault breccia contains locally derived clasts up to 4 cm across in a matrix of comminuted clay. Fragments of fibrous carbonate vein are common in the fault breccia. The presence of large quantities of clay indicates that the fault zone is likely sealed.

The Belliveau Village section contains two major northeast-trending faults, the Belliveau Fault (St. Peter 1992, 1993) and the Saint-Joseph Fault. The Saint-Joseph Fault separates Albert and Weldon Formation rocks. Albert Formation shales to the northwest of the Saint-Joseph Fault form shale-clast breccias. Microstructural analysis reveals that the shale-clast breccias consist of angular fragments of shale cemented with fine-grained calcite. The rock is clast-supported and clasts often contain internal fractures. Drag of Weldon Formation bedding into the Saint-Joseph Fault indicates dextral movement. The Belliveau Fault has Weldon Formation rocks in both hangingwall and footwall, and is probably not a regionally significant structure. Steeply plunging en-echelon folds and subhorizontal slickenlines in the Belliveau Fault zone indicate that movement on this fault was dominantly dextral.

Taylor Village section

At Taylor Village (Figure 2, area 5), a 500–600 m long section of Albert Formation rocks is exposed on the southwest bank of the Memramcook River. In comparison to the nearby Boudreau Village and Belliveau Village sections, the Taylor Village section is little deformed. However, the section is cut by a number of small faults that have associated small-scale drag folds. There may also be a more important fault in the unexposed interval that occurs at approximately the mid-point of the section. Both reverse and normal faults were identified on the basis of drag folds. No evidence for strike-slip movement was observed on any of the faults, in contrast to the Boudreau and Belliveau sections. When plotted on a stereonet (Figure 3e), bedding measurements at Taylor Village define a partial girdle, indicating that the Taylor Village rocks probably form the southern limb of a large-scale, shallowly westward-plunging anticline.

SEISMIC INTERPRETATION

Seismic reflection surveys were run in the study area by Chevron Canada Resources Ltd. in the mid-1980s. The 2D lines were reprocessed by Shell Canada Limited in 1998–1999 to assist the company in choosing locations for a nine-hole core drilling program for oil shales. Interpretations of the reprocessed lines were reported by Lynch (1999). However, the seismic reflection profile interpretations of Lynch (1999) are supported only in part by field evidence. Although both field and map evidence indicates that numerous faults should cut the profiles, few faults appear on the interpretations. The interpretations also emphasize low-angle faults, while outcrop and map evidence indicates that most faults in the area are steep, at least in their near-surface expression. Two key northwest-trending lines, AT4-1947 (L1 on Figure 2) and AT4-1949 (L2 on Figure 2), have been reinterpreted in the light of field and map evidence (Figures 10 and 11).

Reinterpretation of the seismic lines shows the importance of both high-angle and low-angle faults. On the interpreted line AT4-1947 (Figure 10) the Caledonia, Round Hill and Hillsborough faults appear as

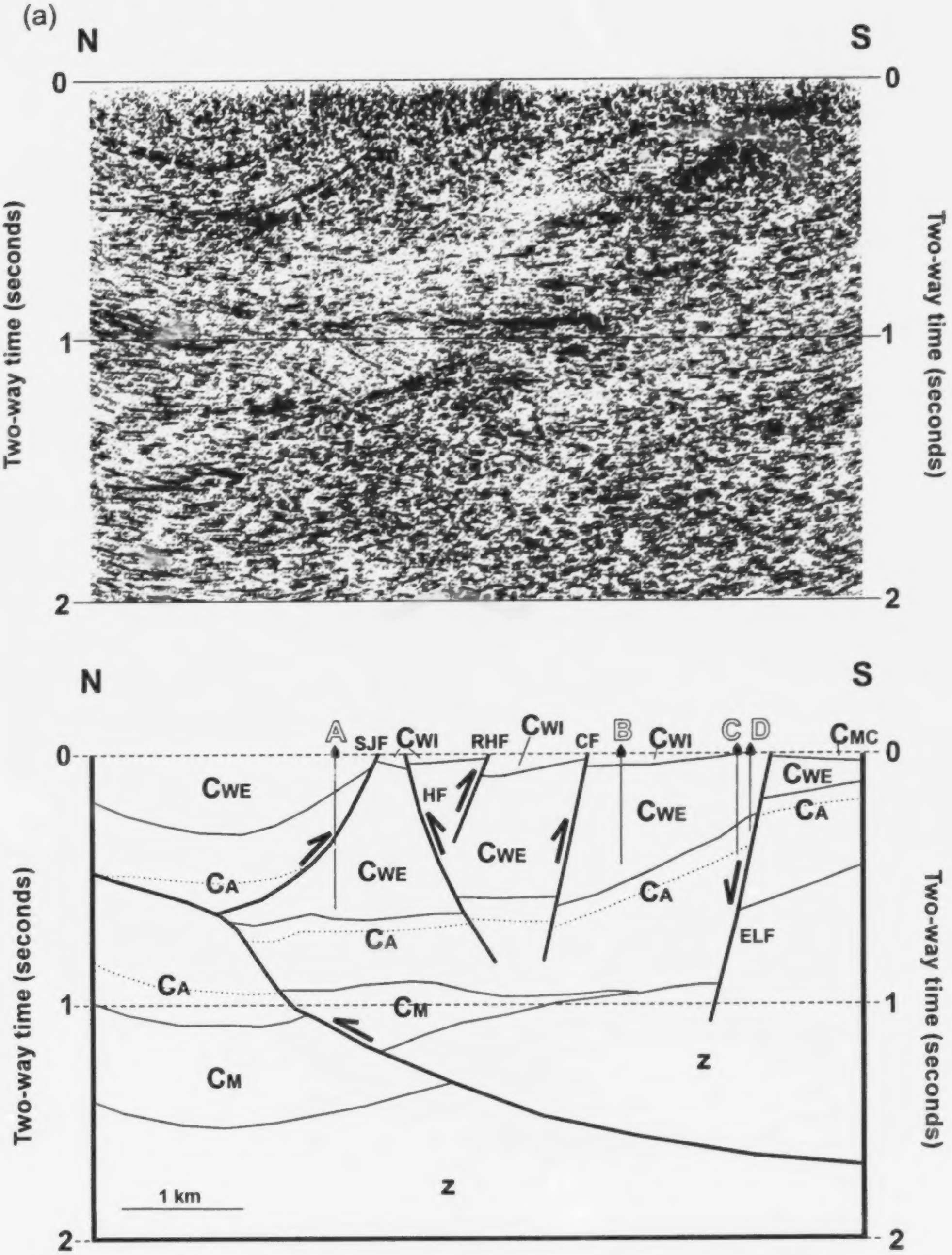


Figure 10. (a) Seismic reflection profile for seismic line AT4-1947 (L1 on Figure 2). (b) Interpretation of seismic line AT4-1947. Rock units: **CMC** – Mabou and Cumberland Groups; **CWI** – Windsor Group; **CWE** – Weldon Formation; **CA** – Albert Formation; **CM** – Memramcook Formation; and **Z** – basement. Faults: **SJF** – Saint-Joseph Fault, **HF** – Hillsborough Fault, **RHF** – Round Hill Fault, **CF** – Caledonia Fault, **ELF** – Edgetts Landing Fault. Borehole control is provided by: **A** – Imperial/New Brunswick Oilfields Hillsborough 1; **B** – Shell Albert Mines 3; **C** – Shell Albert Mines 1; and **D** – Canadian Occidental Albert Mines 81-8. Dotted lines indicate the interpreted position of the top of the Frederick Brook Member.

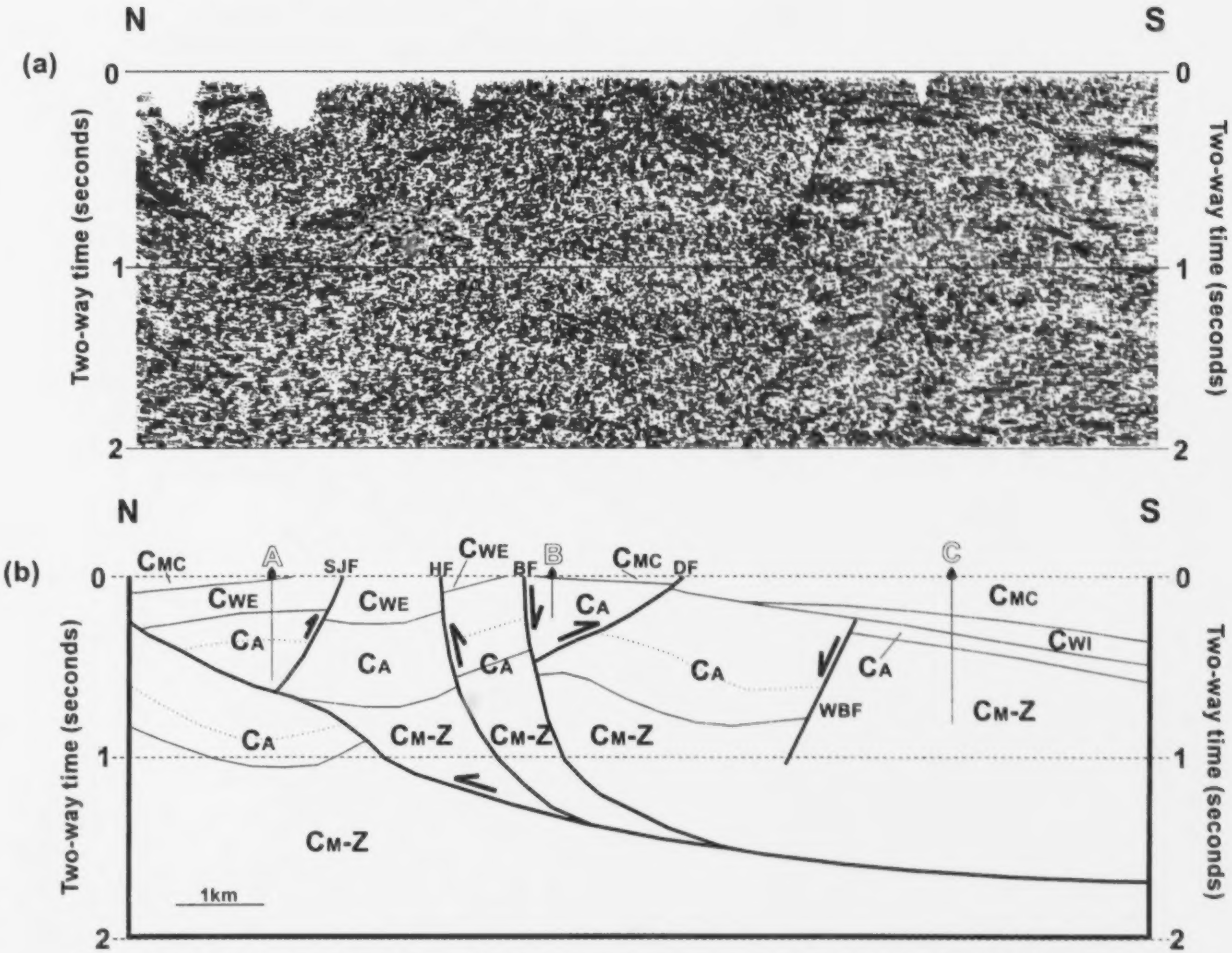


Figure 11. (a) Seismic reflection profile for the northwestern part of seismic line AT4-1949 (L2 on Figure 2). (b) Interpretation of seismic line AT4-1949. Rock units: **CMC** – Mabou and Cumberland groups; **CWI** – Windsor Group; **CWE** – Weldon Formation; **CA** – Albert Formation; **CM-Z** – Memramcook Formation and/or basement. Faults: **SJF** – Saint-Joseph Fault, **HF** – Hillsborough Fault, **BF** – Boudreau Fault, **DF** – Dorchester Fault, **WBF** – Wilson Brook Fault. Borehole control is provided by: **A** – Shell/New Brunswick Oilfields Belliveau 1; **B** – Shell Boudreau 1; and **C** – Columbia Beaumont L-24. Dotted lines indicate the interpreted position of the top of the Frederick Brook Member.

steep faults. A low-angle thrust fault duplicates the Albert Formation at the north end of the line, and appears to sole into basement to the south. The Saint-Joseph Fault is interpreted to be a backthrust associated with the low-angle fault. Duplication of the Weldon Formation by the Saint-Joseph Fault is recorded in the Imperial/New Brunswick Oilfields Hillsborough 1 well (St. Peter 2001b). Further borehole control is provided by Shell Albert Mines 1 and 3, and Canadian Occidental Albert Mines 81-8 (St. Peter 2001b). On the interpreted line AT4-1949 (Figure 11) a similar geometry is seen, with the Round Hill, Boudreau, Hillsborough and Wilson Brook faults appearing as steep structures. In a similar way to AT4-1947, a low-angle fault is imaged which soles into basement to the south, and the Saint-Joseph Fault is interpreted to be a backthrust associated with this low-angle fault. The Dorchester Fault also appears as a northward-dipping thrust fault in this interpretation. The Wilson Brook Fault is an important basin-controlling structure, with a highly condensed Albert Formation section appearing to the south. Borehole control is provided by the Shell Boudreau 1, Shell/New Brunswick Oilfields Belliveau 1 and Columbia Beaumont L-24 boreholes (St. Peter 2001b).

It is important to bear in mind that outcrop and map evidence shows that strike-slip movements are important on northeast-trending faults in the area. Thus problems may occur when extending interpretations of 2D seismic profiles outside the plane of the profile.

REGIONAL IMPLICATIONS

The Maritimes Basin has been described as a pull-apart basin associated with dextral movement on northeast-trending faults, followed by transpression and basin inversion around a restraining bend in the Cobequid–Chedabucto Fault system during dextral-oblique collision of Laurentia and Gondwana (e.g., Webb 1963; Bradley 1982; Mosher and Rast 1984; Nance and Warner 1986; Nance 1987; Foley 1989; St. Peter 1992, 1993). Nickerson (1994) proposed a model whereby the Maritimes Basin formed in response to oblique-extensional collapse of the Acadian orogen, followed by a prolonged period of dextral wrench tectonics, possibly continuing into the Permian. This study provides evidence to broadly support these dextral models, but also shows that the models do not explain all the observed features in the study area.

Evidence for the presence of Devonian–Carboniferous dextral strike-slip motion on the major bounding faults of the Moncton Subbasin has been published by a number of workers. For example, the Belleisle Fault was thought to be dextral by Webb (1963, 1969) based on the orientations of folds and small faults associated with the main fault. This interpretation was supported by the mesofracture analysis of Leger (1987). However, it should be noted that other authors consider there to be evidence for predominantly dip-slip motion on the Belleisle fault (Gussow 1953; Garnett and Brown 1973). Others concede the possibility of limited dextral movement (McCutcheon and Robinson 1987). Leger (1987) observing a dextral brittle overprint of mylonitic rocks associated with the Kennebecasis Fault in the Pocologan Harbour area. The Clover Hill and Caledonia faults were also considered to be probable dextral strike-slip faults on the basis of structural and geophysical data (Webb 1969; Leger 1987; Foley 1989). This study provides evidence that movement on faults in the study area, such as the Saint-Joseph Fault, Hillsborough Fault and Belliveau Fault, has been dominantly dextral.

However, sinistral fault movements have also been noted in southern New Brunswick. Minor post-Windsor Group sinistral displacement is observed on the Caledonia Fault and a small sinistral displacement of Cumberland Group rocks is observed on the Edgetts Landing fault (St. Peter and Johnson 1997; see Figure 2). Webb (1963) proposed a 17 km post-Mabou Group sinistral displacement on the Dennis Beach Fault near Waterside, based on offset of Mabou Group alluvial fans, and offset and asymmetrically folded clasts in Mabou Group rocks at Dennis Beach. While the basis for the 17 km offset has been questioned on sedimentological grounds (van de Poll 1994) and because of basement clast types included in the Hopewell Cape Formation (St. Peter, personal communication, 2001), a smaller sinistral displacement (on the order of 1 or 2 km) is nonetheless likely. This study provides evidence for dominantly sinistral movement on faults associated with the Boudreau deformation zone. Thus there is evidence for sinistral movements of probable Carboniferous age on several faults in southern New Brunswick.

It has not been possible to definitively establish the relative timing of dextral and sinistral fault movements. However, circumstantial evidence suggests that sinistral movements are later than dextral movements. Sinistral movement on the Dennis Beach Fault to the south of the study area (see Figure 1 for location) occurred after deposition of Mabou Group rocks (Webb 1963). Map evidence suggests there is post-Cumberland Group sinistral displacement on the Edgetts Landing Fault (Figure 2). An upper limit for the age of sinistral movements could not be established. Map evidence shows that the Saint-Joseph Fault displays dextral offset of Windsor Group rocks (Figure 2); thus dextral movements continued at least into Windsor time.

Northwest-trending folding in Windsor Group rocks to the east of the Peck Creek and Frederick Brook sections (see Figure 2) is thought to be related to northwest-trending normal faulting (St. Peter 1992, 1993). The major syncline axis is offset sinistrally by the Caledonia Fault and dextrally by the Round Hill Fault. Thus, folding must have occurred prior to the termination of strike-slip movement on northeast-trending faults.

FAULT MECHANISMS

In general the available deformation mechanisms in a given rock mass exert control over the deformation path of that mass (e.g., Lister and Williams 1983; Jiang and White 1995). Available deformation mechanisms are controlled by the material properties of the deforming rocks. Thus rocks with differing material properties will exhibit differing responses to deformation. This can be seen clearly in the differing responses to deformation of Albert Formation shales, Weldon Formation silt/mudstones and Albert Formation conglomerates in the study area. Albert Formation shales possess a well-developed planar anisotropy, whereas Weldon Formation mudrocks are much more isotropic. Albert Formation shales tend to be folded into parallelism with fault zones resulting in displacements being accommodated along the pre-existing planar anisotropy. This leads to the formation of wide deformation zones comprising numerous steep bedding-parallel faults, as at domain 2 of the Boudreau Village section. In contrast, Weldon Formation rocks have a less well-developed planar anisotropy; they respond to fault deformation by forming a new planar anisotropy that can accommodate slip, in the form of the localized fracture cleavage observed at Peck Creek (Figure 6, locality 6) and at the Belliveau Village section. Albert Formation conglomerates can deform by particulate flow, thus appearing relatively undeformed even within fault zones, as in polymictic conglomerates observed at Peck Creek (Figure 5d; Figure 6, locality 2). Thus fault zones in the study area show a broad variation in deformational style both along strike and down dip, depending on the rock types the fault zones cut.

Thin section analysis indicates that deformation micro-processes within fault zones have been complex, involving interactions between brittle and ductile processes, possibly acting over long time periods. In general, rocks from both northeast- and northwest-trending fault zones show multiple periods of fracturing and carbonate vein emplacement and in many cases incorporate mylonitic fragments. Carbonate veins tend to localize deformation because they are less competent than their wall rocks. The prevalence of carbonate veins and carbonate-sealed fractures suggests that enhanced permeabilities within fault zones have in general been transient. Faults acted as conduits for fluids during deformation events but became sealed soon afterwards.

IMPLICATIONS FOR PETROLEUM EXPLORATION

While 2D seismic profiles have undoubtedly contributed greatly to the elucidation of structure in the area, knowledge of detailed geometry is still lacking. The presence of significant strike-slip displacements and numerous steep faults limits the ability of 2D profiles to establish an accurate 3D picture. A high-resolution 3D seismic survey of the area may be the only way to resolve the structural complexity.

Bitumen-saturated Mabou Group rocks at Frederick Brook (Figure 6, locality 5) indicate that hydrocarbon migration occurred after Mabou Group deposition. It is speculated that hydrocarbon migration could be contemporaneous with movement on northeast-trending faults. Northeast-trending albertite veins were observed at Frederick Brook (Figure 6, locality 7). Evidence cited above suggests that some northeast-trending faults may have been undergoing sinistral transpression at this time. Sinistral displacement of hydrocarbon veinlets from Boudreau Village thin sections provide some evidence to support this hypothesis. Therefore, source and reservoir rocks may show net sinistral displacements across these faults.

It is important to note that northeast-trending faults in the study area have conflicting senses of net displacement. For example, some northeast-trending faults show net sinistral displacements of Windsor Group rocks, while others show net dextral displacements. Thus, it is impossible to apply a single model to resolve the complex movement history of the northeast-trending faults in the area. Detailed analysis of the sense and timing of movement(s) on individual faults is required.

CONCLUSIONS

Tectonic events that have affected Carboniferous rocks in the study area are:

1. A period of early macroscopic to mesoscopic folding with northeast-trending axial planes, which deformed Horton Group strata but pre-dated the Windsor Group.

2. Low-angle thrusting, possibly related to the early stages of dextral transpression. Evidence for this can be seen in steepened structures at Boudreau Village domain 2 and in the bedding-parallel deformation seen to the north of the Saint-Joseph Fault at Belliveau Village.

3. Dextral transpression on northeast-trending faults throughout the study area. This deformation persisted until post-Windsor times and was responsible for positive flower structure development and basin inversion. This event occurred post-Horton Group and pre-Windsor Group and is responsible for the Horton–Windsor unconformity.

4. Northwest-trending folding of Windsor Group rocks, possibly associated with normal movement on northwest-trending faults. Continuing dextral movement on northeast-trending faults, and segmentation of northwest-trending faults.

5. Sinistral readjustment leading to net sinistral displacements in the south part of the study area in post-Mabou Group (and probably post-Cumberland Group) time.

6. Late east-trending normal faulting, possibly Mesozoic in age and, if so, related to continental break-up during formation of the Atlantic Ocean.

Many of the faults in the study area have experienced multiple periods of movement and interactions between brittle and ductile processes over long time periods. Different rock types have responded to deformation in different ways, leading to variations in fault-zone properties both along-strike and down-dip. The ubiquitous presence of carbonate veins in fault rocks indicates that permeabilities associated with fault movements have likely been transient: most major faults are probably currently sealed in the deep subsurface.

Reinterpretation of northwest-trending 2D seismic profiles reveals the importance of both high-angle and low-angle faults. However, the presence of strike-slip movements and numerous steep faults means that 3D seismic surveys should be considered in the study area to help resolve some of the complexities of structure. Net sinistral displacements of Albert Formation source and reservoir rocks across northeast-trending faults should be considered a possibility. The northeast-trending faults in the study area will have complex movement histories; it is not possible to indiscriminately apply one model to all faults.

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REFERENCES

BARR, S.M., and WHITE, C.E. 1996. Contrasts in late Precambrian–early Paleozoic tectonothermal history between Avalon composite terrane sensu stricto and the other possible peri-Gondwanan terranes in southern New Brunswick and Cape Breton Island, Canada. *In* Avalonia and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. *Edited by* R.D. Nance and M.D. Thompson. Geological Survey of America, Special Paper 304, pp. 95–108.

BELL, W.A. 1929. Horton–Windsor district, Nova Scotia. Geological Survey of Canada, Memoir 155, 268 p.

BRADLEY, D.C. 1982. Subsidence in Late Paleozoic basins in the northern Appalachians. Tectonics, **1**: 107–123.

CARR, F.A. 1968. Stratigraphy and spore assemblages, Moncton map area, New Brunswick. Geological Survey of Canada, Paper 67-29, 47 p.

CARTER, D.C., and PICKERILL, R.K. 1985a. Algal swamp, marginal and shallow evaporitic lacustrine lithofacies from the Late Devonian–Early Carboniferous Albert Formation, southeast New Brunswick, Canada. Maritime Sediments and Atlantic Geology, **21**: 69–86.

CARTER, D.C., and PICKERILL, R.K. 1985b. Lithostratigraphy of the Late Devonian–Early Carboniferous Horton Group of the Moncton Subbasin, southern New Brunswick. Maritime Sediments and Atlantic Geology, **21**: 11–24.

CARTER, D.C., and PICKERILL, R.K. 1985c. A review of the Carboniferous Albert Formation oil shales, New Brunswick: Discussion. Bulletin of Canadian Petroleum Geology, **33**: 261–262.

Foley, S.L. 1989. Geology of the Stoney Creek oil and gas field, and its implications for the tectonic evolution of the eastern Moncton Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Geoscience Report 89-1, 77 p.

Garnett, J.A., and Brown, R.L. 1973. Fabric variation in the Lubec–Belleisle Zone of southern New Brunswick. Canadian Journal of Earth Science, **10**: 1591–1602.

Greiner, H.R. 1962. Facies and sedimentary environments of Albert shale, New Brunswick. American Association of Petroleum Geologists Bulletin, **69**: 767–780.

Greiner, H.R. 1974. The Albert Formation of New Brunswick: a Palaeozoic lacustrine model. Geologische Rundschau, **63**: 1102–1113.

Gussow, W.C. 1953. Carboniferous stratigraphy and structural geology of New Brunswick, Canada. American Association of Petroleum Geologists Bulletin, **37**: 1713–1816.

Harding, T.P. 1985. Seismic characteristics and identification of negative flower structures, positive flower structures and positive structural inversion. American Association of Petroleum Geologists Bulletin, **69**: 582–600.

Jiang, D., and White, J.C. 1995. Kinematics of rock flow and the interpretation of geological structure, with particular reference to shear zones. Journal of Structural Geology, **17**: 1249–1265.

Leger, A. 1987. Transcurrent faulting, southern New Brunswick. Unpublished M.Sc. thesis, University of New Brunswick, Fredericton, New Brunswick, 170 p.

Lister, G.S., and Williams, P.F. 1983. The partitioning of deformation in flowing rock masses. Tectonophysics, **92**: 1–33.

Lynch, G. 1999. Shell Canada Limited Albert oil shales geological results from slim hole drilling program, 1998–1999. Shell Canada Ltd., 33 p.

Macauley, G., Ball, F.D., and Powell, T.G. 1984. A review of the Carboniferous Albert Formation oil shales, New Brunswick. Bulletin of Canadian Petroleum Geology, **32**: 27–37.

Macauley, G., and Ball, F.D. 1985. A review of the Carboniferous Albert Formation oil shales, New Brunswick: Reply. Bulletin of Canadian Petroleum Geology, **33**: 263.

McCutcheon, S.R. 1981. Stratigraphy and paleogeography of the Windsor Group in southern New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Division, Open File 81-31, 210 p.

McCutcheon, S.R., and Robinson, P.T. 1987. Geological constraints on the genesis of the Maritimes Basin, Atlantic Canada. *In* Sedimentary Basins and Basin Forming Mechanisms. *Edited by* C. Beaumont and A.J. Tankard. Canadian Society of Petroleum Geologists, Memoir 12, pp. 287–297.

Mosher, S. and Rast, N. 1984. The deformation and metamorphism of Carboniferous rocks in Maritime Canada and New England. *In* Variscan Tectonics of the North Atlantic Region. *Edited by* D.H.W. Hutton and D.J. Sanderson. Geological Society of London, Special Publication 14, pp. 233–244.

Nance, R.D. 1987. Dextral transpression and Late Carboniferous sedimentation in the Fundy coastal zone of southern New Brunswick. Canadian Society of Petroleum Geologists, Memoir 12, pp. 363–377.

Nance, R.D. and Warner, J.B. 1986. Variscan tectonostratigraphy of the Mispec Group, southern New Brunswick: Structural geometry and deformational history. *In* Current Research, part A. Geological Survey of Canada, Paper 86-1A, pp. 351–358.

NICKERSON, W.A. 1994. Geophysical constraints on the stratigraphy, structure and tectonic evolution of the Late Devonian/Carboniferous Moncton subbasin, New Brunswick. Unpublished Ph.D thesis, Memorial University of Newfoundland, St. John's, Newfoundland and Labrador, 306 p.

ST. PETER, C. 1992. Lithologic facies, seismic facies, and strike-slip setting of the Lower Carboniferous alluvial/ fluvial/lacustrine Albert Formation of New Brunswick. Unpublished M.Sc. thesis, University of New Brunswick, Fredericton, New Brunswick, 229 p.

ST. PETER, C. 1993. Maritimes Basin evolution: Key geologic and seismic evidence from the Moncton Subbasin of New Brunswick. Atlantic Geology, **29**: 233–270.

ST. PETER, C. 2001a. Petroleum geology in the Carboniferous of southeastern New Brunswick. *In* New England Intercollegiate Geology Conference, Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R.K. Pickerill and D. Lentz. pp. A4-1–A4-30.

ST. PETER, C. 2001b. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p.

ST. PETER, C. and JOHNSON, S.C. 1997. Carboniferous geology of the Hillsborough area (NTS 21 H/15), Albert and Westmorland counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 97-8 (revised 2000).

VAN DE POLL, H.W. 1994. Carboniferous provenance and lithostratigraphy of the Chignecto Bay region, New Brunswick: a preliminary assessment. *In* Current Research 1993. *Edited by* S.A.A. Merlini. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Miscellaneous Report 12, pp. 188–201.

VAN DE POLL, H.W. 1995. Upper Palaeozoic rocks: New Brunswick, Prince Edward Island and Îles de la Madeleine. *In* Chapter 5 of Geology of the Appalachian–Caledonian Orogen in Canada and Greenland. *Edited by* H. Williams. Geological Survey of Canada, Geology of Canada, no. 6, 455–492.

WEBB, G.W. 1963. Occurrence and exploration significance of strike-slip faults in southern New Brunswick, Canada. Bulletin of the American Association of Petroleum Geologists, **47**: 1904–1927.

WEBB, G.W. 1969. Paleozoic wrench faults in the Canadian Appalachians. *In* North Atlantic Geology and Continental Drift. *Edited by* M. Kay. American Association of Petroleum Geologists, Memoir 12, pp. 754–786.

WILLIAMS, H.1979. Appalachian orogen in Canada. Canadian Journal of Earth Sciences, **16**: 792–807.

WOODCOCK, N.H. and FISCHER, M. 1986. Strike-slip duplexes. Journal of Structural Geology, **8**: 725–735.

WOODCOCK, N.H. and SCHUBERT, C. 1994. Continental strike-slip tectonics. *In* Continental Deformation. *Edited by* P.L. Hancock. pp. 251–263.

GEOLOGY OF THE SQUAW CAP AREA (NTS 21 O/15d, e, f), RESTIGOUCHE COUNTY, NEW BRUNSWICK †

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The Squaw Cap area is underlain by Middle Paleozoic sedimentary and minor volcanic rocks that are divided into two conformable successions separated by a Late Silurian (Salinic) erosional disconformity. The lower succession comprises a turbiditic sequence deposited in a fore-arc setting, and includes the Upper Ordovician Grog Brook Group, and overlying Upper Ordovician to Lower Silurian Matapédia Group, and Lower Silurian Upsalquitch Formation (Chaleurs Group). The upper succession consists of sedimentary and volcanic rocks of the Dalhousie Group, including uppermost Silurian to Lower Devonian sedimentary rocks of the Indian Point Formation, and overlying Lower Devonian volcanic rocks of the Archibald Settlement Formation. The Grog Brook Group comprises the Boland Brook Formation (dark grey, thin-bedded, noncalcareous mudstone, siltstone and fine-grained sandstone) and conformably overlying Whites Brook Formation (medium grey, thin- to thick-bedded, typically calcareous sandstone with thin interbeds of dark grey noncalcareous shale). The Matapédia Group is divided into the Pabos Formation (mainly dark grey, thin-bedded calcareous siltstone and silty calcilutite, with local thicker-bedded sequences dominated by calcareous sandstone) and overlying White Head Formation (dark grey, thin-bedded calcilutite and minor calcareous shale and siltstone). The Upsalquitch Formation is composed mainly of medium grey, thin-bedded calcareous siltstone and fine-grained sandstone. Above the Salinic disconformity, the Indian Point Formation comprises thin- to thick-bedded, locally fossiliferous, calcareous siltstone, fine-grained sandstone, calcarenite, and minor biostromal limestone, conglomerate, red siltstone, and mafic volcanic rocks. The Indian Point Formation is conformably overlain by within-plate tholeiitic mafic to intermediate flows and flow breccias of the Archibald Settlement Formation.

The effects of Salinic tectonism in the Squaw Cap area are reflected in uplift and erosive removal of most of the Upsalquitch Formation west of the McKenzie Gulch Fault. The latter probably developed as a synsedimentary normal fault in the Late Silurian, based on the presence of polymictic conglomerate beds in a thickened Indian Point section east of the fault. Post-Early Devonian (Acadian) orogenic events have produced open to close folds with northeast-trending axes; moderate, and weak to very weak axial planar cleavage is developed in the older and younger rock sequences, respectively. West of the Sellarsville Fault, the Chessers Brook Syncline plunges shallowly to the southwest, whereas east of the fault, the Coxs Brook Anticline, Restigouche Syncline, and Val-Melanson Anticline plunge to the northeast at angles of 30–40°. The Sellarsville Fault is a reverse fault of probable Middle Devonian age, along which older rocks to the west have been emplaced over younger rocks to the east. It is offset by the dextral strike-slip Squaw Cap Fault.

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† New Brunswick Geological Surveys Branch ordinary budget.

Thermal maturity, as determined by vitrinite reflectance and thermal alteration indices of palynomorphs, is variable in the Indian Point Formation, but two samples west of the McKenzie Gulch Fault fall within the oil window. Strata of similar age and lithology in the Gaspé Peninsula are known to contain hydrocarbons.

Le secteur du cap Squaw repose sur des roches sédimentaires et une quantité réduite de roches volcaniques du Paléozoïque moyen qui se subdivisent en deux cortèges concordants séparés par une discordance d'érosion (salinique) du Silurien tardif. Le cortège inférieur comporte une séquence turbiditique s'étant déposée dans un milieu avantarc et il comprend le groupe de l'Ordovicien supérieur du ruisseau Grog et le groupe susjacent de l'Ordovicien supérieur au Silurien inférieur de Matapédia, ainsi que la Formation du Silurien inférieur d'Upsalquitch (groupe de Chaleurs). Le cortège supérieur est constitué de roches sédimentaires et volcaniques du groupe de Dalhousie, notamment les roches sédimentaires supérieures du Silurien au Dévonien inférieur de la Formation d'Indian Point et des roches volcaniques susjacentes du Dévonien inférieur de la Formation d'Archibald Settlement. Le groupe du ruisseau Grog est composé de la Formation du ruisseau Boland (grès à grain fin, siltstone et mudstone non calcaire en strates minces gris foncé) et de la Formation susjacente concordante de Whites Brook (grès habituellement calcaire en strates minces à épaisses gris moyen interlité de strates minces de schiste non calcaire gris foncé). Le groupe de Matapédia se subdivise en deux éléments : la Formation de Pabos (principalement du siltstone calcaire en strates minces gris foncé et de la calcilutite silteuse, avec séquences locales de strates plus épaisses dans lesquelles prédomine le grès calcaire) et la Formation susjacente de White Head (calcilutite en strates minces gris foncé et quantité réduite de siltstone et de schiste calcaire). La Formation d'Upsalquitch est principalement constituée de grès à grain fin et de siltstone calcaire en strates minces gris moyen. Audessus de la discordance salinique, la Formation d'Indian Point est formée de siltstone calcaire localement fossilifère en strates minces à épaisses, de grès à grain fin, de calcarénite et d'une quantité restreinte de chaux biostromale, de conglomérat, de siltstone rouge et de roches volcanomafiques. La Formation d'Indian Point est recouverte de façon concordante de brèches de coulées de lave et de coulées mafiques à intermédiaires tholéiitiques intraplaques de la Formation d'Archibald Settlement.

Les effets du diastrophisme salinique dans le secteur du cap Squaw transparaissent dans l'extraction par soulèvement et par érosion de la majeure partie de la Formation d'Upsalquitch à l'ouest de la faille du ravin McKenzie. Cette dernière est probablement apparue sous la forme d'une faille normale synsédimentaire au cours du Silurien tardif, si l'on s'appuie sur la présence des couches de conglomérat polymictique dans une section épaissie d'Indian Point à l'est de la faille. Des phénomènes orogéniques ultérieurs au Dévonien inférieur (phase acadienne) ont produit des plis ouverts à serrés selon des axes orientés vers le nord-est; une schistosité suivant un plan axial modéré et faible à très faible est présente dans les séquences de roches anciennes et jeunes, respectivement. À l'ouest de la faille de Sellarsville, le pli synclinal du ruisseau Chessers plonge peu profondément vers le sud-ouest, tandis qu'à l'est de la faille, le pli anticlinal du ruisseau Coxs, le pli synclinal de Restigouche et le pli anticlinal de Val-Melanson plongent vers le nord-est suivant des angles de 30 à 40 degrés. La faille de Sellarsville est une faille inverse remontant probablement au Dévonien moyen le long de laquelle les roches âgées à l'ouest se sont déposées audessus des roches plus récentes à l'est. Elle se trouve décalée par la faille décrochante dextre du cap Squaw.

INTRODUCTION

Geological mapping in Restigouche County is conducted under the auspices of the NATMAP (NATional MAPping program)-funded Appalachian Foreland and Platform Project. This work has been undertaken in order to acquire an improved understanding of the geological history, and the mineral and hydrocarbon potential of the Late Ordovician–Middle Devonian Gaspé Belt. A further objective is to produce a "seamless" picture of the geology across the New Brunswick–Québec border, employing common stratigraphic nomenclature whenever possible. Along the Restigouche River in the Squaw Cap area (Figure 1), the stratigraphic affiliation of many rocks is unclear, and discrepancies exist in the respective geologial maps of northern New Brunswick and the Gaspé Peninsula. Detailed mapping was carried out in the summer of 2001 in order to correlate the stratigraphy and structure with the better known successions in Québec, and to facilitate interpretation of the geological history of this area.

REGIONAL SETTING

The rocks underlying the Squaw Cap area constitute part of the Gaspé Belt (Bourque *et al.* 1995), or Matapédia Cover Sequence of Fyffe and Fricker (1987) and van Staal and de Roo (1995). The Gaspé Belt is a Middle Paleozoic successor basin underlain by deformed, Early Paleozoic rocks of the Laurentian margin (Humber Zone) and the Iapetan oceanic tract (Dunnage Zone)(van Staal and de Roo 1995; Malo and Bourque 1993). It extends from eastern Gaspé Peninsula in Québec, southwest through northwestern New Brunswick to northeastern Maine, USA, and encompasses Upper Ordovician to Middle Devonian rocks that are commonly consigned to one of three major structural divisions, namely, the Connecticut Valley–Gaspé Synclinorium, Aroostook–Percé Anticlinorium, and Chaleur Bay Synclinorium (Rodgers 1970)(Figure 1). The rocks discussed herein constitute part of the Aroostook–Percé Anticlinorium and Chaleur Bay Synclinorium, and occur in the hinge area of the Restigouche Syncline, a structural subdivision of the Chaleur Bay Synclinorium at the head of Chaleur Bay (Figure 1).

The Aroostook–Percé Anticlinorium extends from Percé to Matapédia in the Gaspé Peninsula, transects northwestern New Brunswick and continues into northeastern Maine (Figure 1). Upper Ordovician to Lower Silurian rocks of the Aroostook–Percé Anticlinorium comprise deep-water turbidite deposits that are broadly divided into a lower siliciclastic assemblage and an upper carbonate assemblage. The siliciclastic rocks have been assigned to the Garin Formation in Québec (Malo 1988) and the Grog Brook Group in northwestern New Brunswick (St. Peter 1978), whereas the carbonate rocks are all assigned to the Matapédia Group (Crickmay 1932; Alcock 1935; Lespérance *et al.* 1987)(Figure 2). The base of the Grog Brook Group is not exposed; however, the Matapédia Group unconformably overlies Middle to Upper Ordovician rocks of the Balmoral Group in northern New Brunswick (Wilson 2000a)(Figure 2). Where not faulted, contacts between Aroostook–Percé rocks, and overlying Silurian to Devonian rocks of the Chaleur Bay Synclinorium, are reported to be conformable (e.g., St. Peter 1978; Bourque *et al.* 1995).

The Chaleur Bay Synclinorium extends from the southeastern part of the Gaspé Peninsula, southwest as far as west-central New Brunswick (Figure 1). In northern New Brunswick, it consists of Silurian to lowermost Devonian sedimentary and volcanic rocks of the Chaleurs Group (Schuchert and Dart 1926; Burk 1964), and Lower to Middle Devonian sedimentary and volcanic rocks of the Dalhousie Group (Clarke 1909; Greiner 1967). The Siluro-Devonian sedimentary record in the Gaspé Peninsula has been

LEGEND

DEVONIAN

× × ×	Light grey, medium-grained diorite.
✚ ✚ ✚	Pink to maroon, aphyric to feldspar-phyric felsite and microgranite.

EARLY DEVONIAN

Dalhousie Group

∧ ∧ ∧	Archibald Settlement Formation: dark green, massive to flow-brecciated basalt, minor felsic volcanic rocks.

SILURO-DEVONIAN

☐	Indian Point Formation: light to medium grey, thin-bedded, locally fossiliferous, calcareous siltstone, fine-grained sandstone, and calcarenite; local medium-bedded fossiliferous sandstone and biostromal limestone; minor red calcareous siltstone, polymictic conglomerate, limestone conglomerate and mafic volcanic rocks.

EARLY SILURIAN

Chaleurs Group

▤	Upsalquitch Formation: greenish grey, thin-bedded calcareous siltstone and fine-grained sandstone.

LATE ORDOVICIAN - EARLY SILURIAN

Matapedia Group

▦	White Head Formation: dark grey, thin-bedded calcilutite, calcareous shale, and calcareous siltstone.

LATE ORDOVICIAN

▧	Pabos Formation: medium to dark grey, thin-bedded calcareous siltstone, mudstone, and minor fine-grained sandstone and calcilutite; light to medium grey, thin- to medium-bedded, fine- to coarse-grained, calcareous to noncalcareous sandstone and minor siltstone are locally abundant in the lower part of the unit.

Grog Brook Group

⁘	Whites Brook Formation: light grey to greenish grey, medium- to thick-bedded, medium-grained, noncalcareous to calcareous sandstone, grit and conglomerate; minor dark grey, thin-bedded, noncalcareous shale and siltstone.
░	Boland Brook Formation: Medium to dark grey, thin- to medium-bedded, noncalcareous siltstone and fine-grained sandstone; minor thick-bedded, dark grey, noncalcareous sandstone, grit, and conglomerate.

———	geological contact
- - - - -	fault
·········	disconformity
✕	syncline
↕	anticline
✱	high-Ca groundwater calcrete occurrence
▲	sample for thermal maturity study (T.A.I. – thermal alteration index; Ro – vitrinite reflectance; C.A.I. – conodont colour alteration index)
④•	location of photograph
⊢A⊣	stratigraphic section discussed in text
a⊢⊣b	location of cross-section(Figure 3)

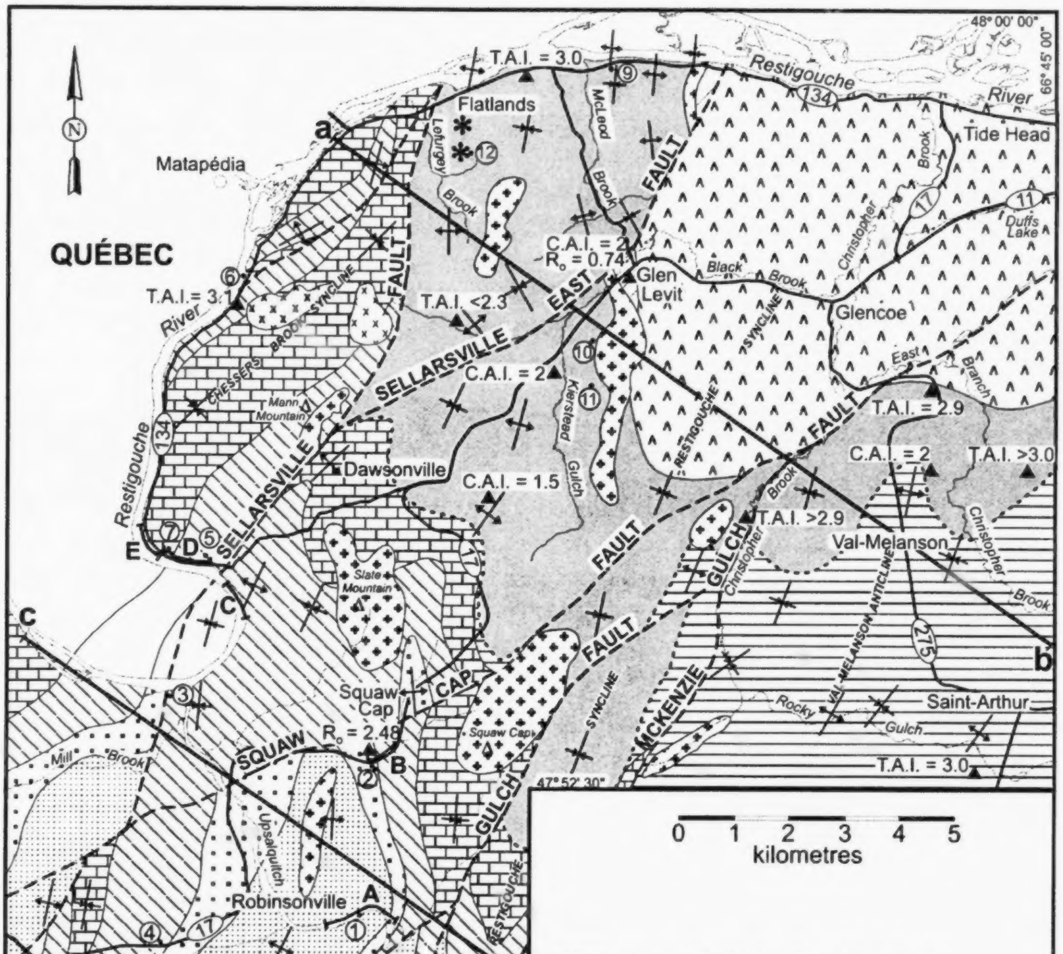


Figure 1. Location and geological map of the Squaw Cap area.

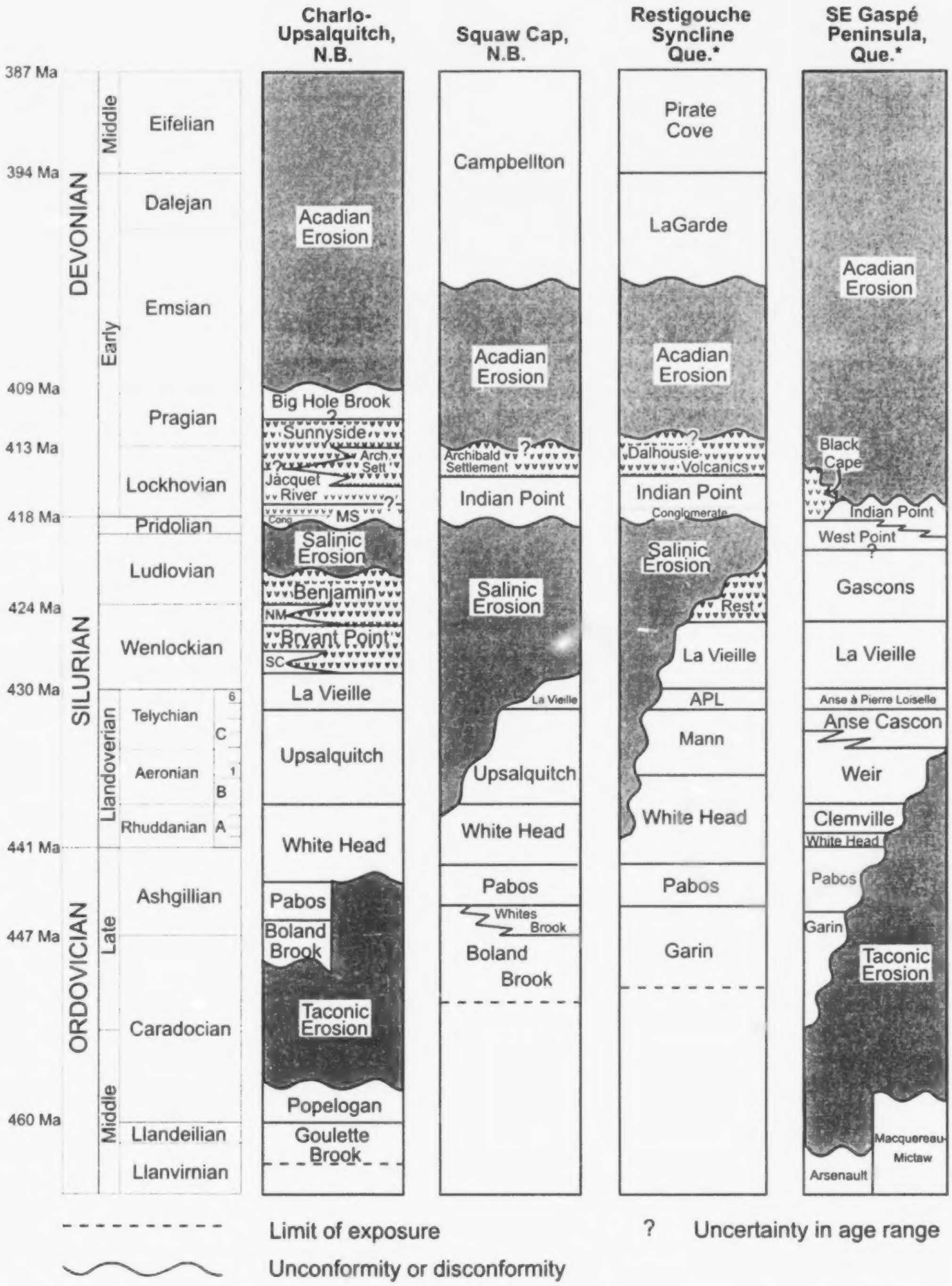


Figure 2. Stratigraphic columns for different parts of the Gaspé Belt in northern New Brunswick and southern Gaspé Peninsula, highlighting erosive gaps in the stratigraphic record associated with major tectonic pulses. "v" pattern indicates volcanic formations. Abbreviations: MS – Mitchell Settlement Formation; SC – South Charlo Formation; NM – New Mills Formation; APL – Anse à Pierre Loiselle Formation; Arch. Sett. – Archibald Settlement Formation; Rest. – Restigouche Volcanics; Cong – conglomerate. * – data from Malo and Bourque (1993) and Bourque *et al.* (2000). Charlo–Upsalquitch data is from Walker and McCutcheon (1995) and Wilson (2000a). Time scale is from Okulitch (1999).

interpreted in terms of up to five major transgressive and regressive phases, corresponding to Llandoverian–Wenlockian successor basin infilling (regression), Wenlockian–Ludlovian basin deepening (transgression), a Ludlovian–Pridolian shallowing (regressive) phase, Lockhovian subsidence (transgression), and, in the eastern Gaspé, continued shallowing through the Early and Middle Devonian (Malo and Bourque 1993; Bourque *et al.* 1995, 2000). This complex depositional history was accompanied by Wenlockian–Ludlovian and Pridolian–Lockhovian intraplate magmatic activity (Dostal *et al.* 1989, 1993), and by Silurian tectonism (Salinic disturbance of Boucot *et al.* 1964; Salinic orogeny of Cawood *et al.* 1995) that appears to have reached its peak during the Late Silurian regressive phase. The Salinic event is manifested by an erosional hiatus of varying duration in different places, although locally there is continuous deposition, suggesting differential uplift and/or sea-level fluctuations.

DESCRIPTION OF STRATIGRAPHIC UNITS

The Squaw Cap area is underlain by two conformable sequences of rocks separated by a Silurian (Salinic) disconformity (Figure 2). The older sequence comprises the Upper Ordovician Grog Brook Group, the Upper Ordovician to Lower Silurian Matapédia Group, and the Lower Silurian Upsalquitch Formation (Chaleurs Group). The Grog Brook Group has been divided into the Boland Brook Formation and overlying Whites Brook Formation, whereas the Matapédia Group, following established nomenclature in Québec, is divided into the Pabos Formation and overlying White Head Formation. Above the Salinic hiatus, the younger sequence consists of the Upper Silurian to Lower Devonian Indian Point Formation and the Lower Devonian Archibald Settlement Formation (Dalhousie Group). The distribution of the various rock units is illustrated in Figure 1.

Grog Brook Group

The Grog Brook Group (St. Peter 1978) comprises a thick series of mainly noncalcareous rocks that underlie the Matapédia Group in northwestern New Brunswick. The Grog Brook Group is widespread in the southwestern part of the study area, occupying the core of the Coxs Brook Anticline from Squaw Cap south to Boland Brook and beyond (Figure 1). Regionally, these rocks occur in the central part of the Aroostook–Percé Anticlinorium, and have been mapped southwest as far as the Maine–New Brunswick border, where they merge with the Madawaska Lake Formation (Roy and Mencher 1976). Poole (1964) regarded these rocks as a lower, noncalcareous division of the Matapédia Group, and Hamilton-Smith (1970) described an unnamed unit of noncalcareous slate below the Carys Mills Formation (equivalent to the Matapédia Group) in the Siegas area of northwestern New Brunswick. St. Peter (1978) mapped the distribution of Poole's lower division in the Restigouche River area and named it the Grog Brook Group. Irrinki and Crouse (1986) and Wilson (1990) mapped parts of the Grog Brook Group in the Sisson Branch Reservoir and Salmon River areas, respectively.

The Grog Brook Group was first divided by Carroll (2000, In preparation), who referred informally to a lower, mudstone-dominated unit and an upper, sandstone-dominated unit. St. Peter (1978) had noted a general increase in coarser-grained material toward the top of the section, but did not define formations according to these criteria. In this paper, the Grog Brook Group is formally divided into the Boland Brook Formation and Whites Brook Formation (new names), which correspond to the mudstone- and sandstone-dominated units, respectively, of Carroll (2000). For a description of regional lithological variations in the Grog Brook Group, the reader is referred to St. Peter (1978).

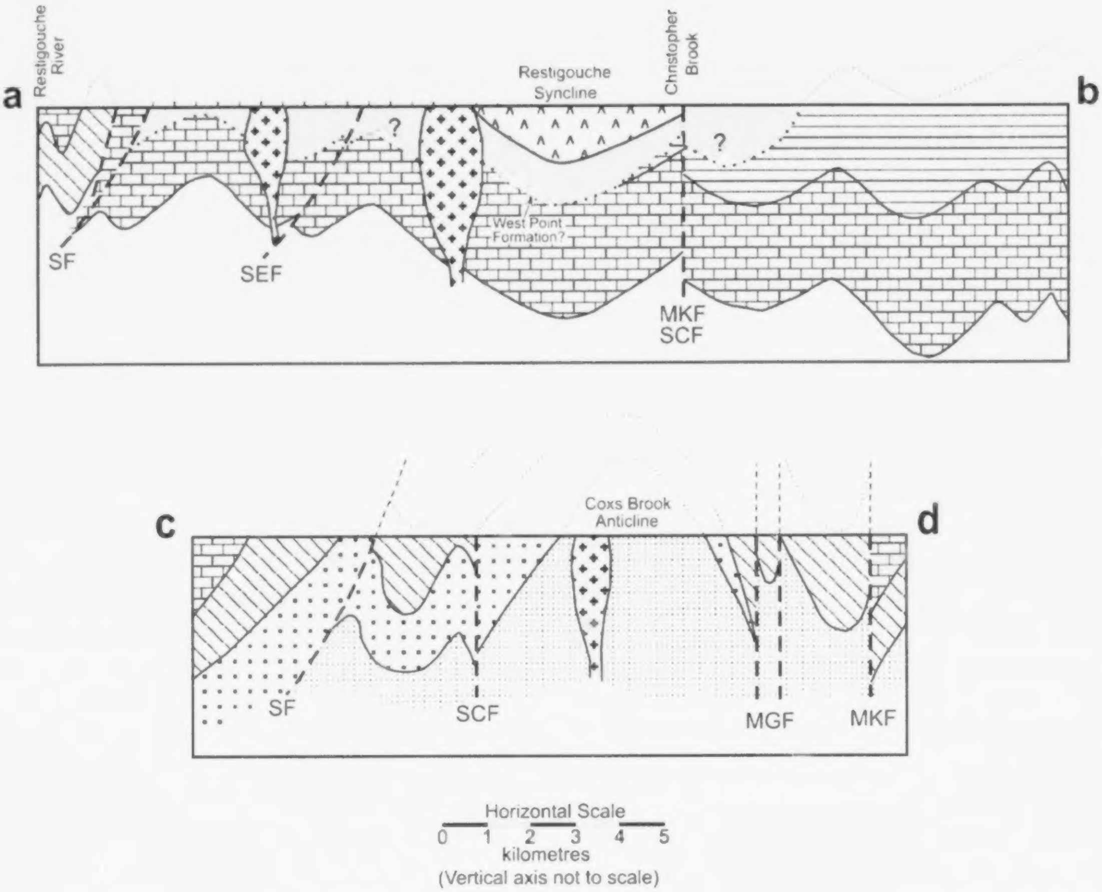


Figure 3. Schematic stratigraphic cross-sections of the Squaw Cap area (see Figure 1 for locations and legend). Note hypothetical occurrence of West Point reefal bodies in subsurface. Abbreviations: **SF** – Sellarsville Fault; **SEF** – Sellarsville East Fault; **MKF** – McKenzie Gulch Fault; **SCF** – Squaw Cap Fault; **MGF** – Manns Gulch Fault.

Boland Brook Formation

The type section of the Boland Brook Formation is located in the upper part of Boland Brook, about 25 km southwest of Squaw Cap Mountain (outside of the survey area). In the Squaw Cap area, exposure is generally poor, except for a few good outcrops on the abandoned rail line that follows Grog Brook, and some excellent sections on Upsalquitch River. One of these extends from 1 km west to 400 m east of Sewells Gulch, a small brook on the north side of Upsalquitch River, and is designated as a reference section for the Boland Brook Formation (Figure 1, section A).

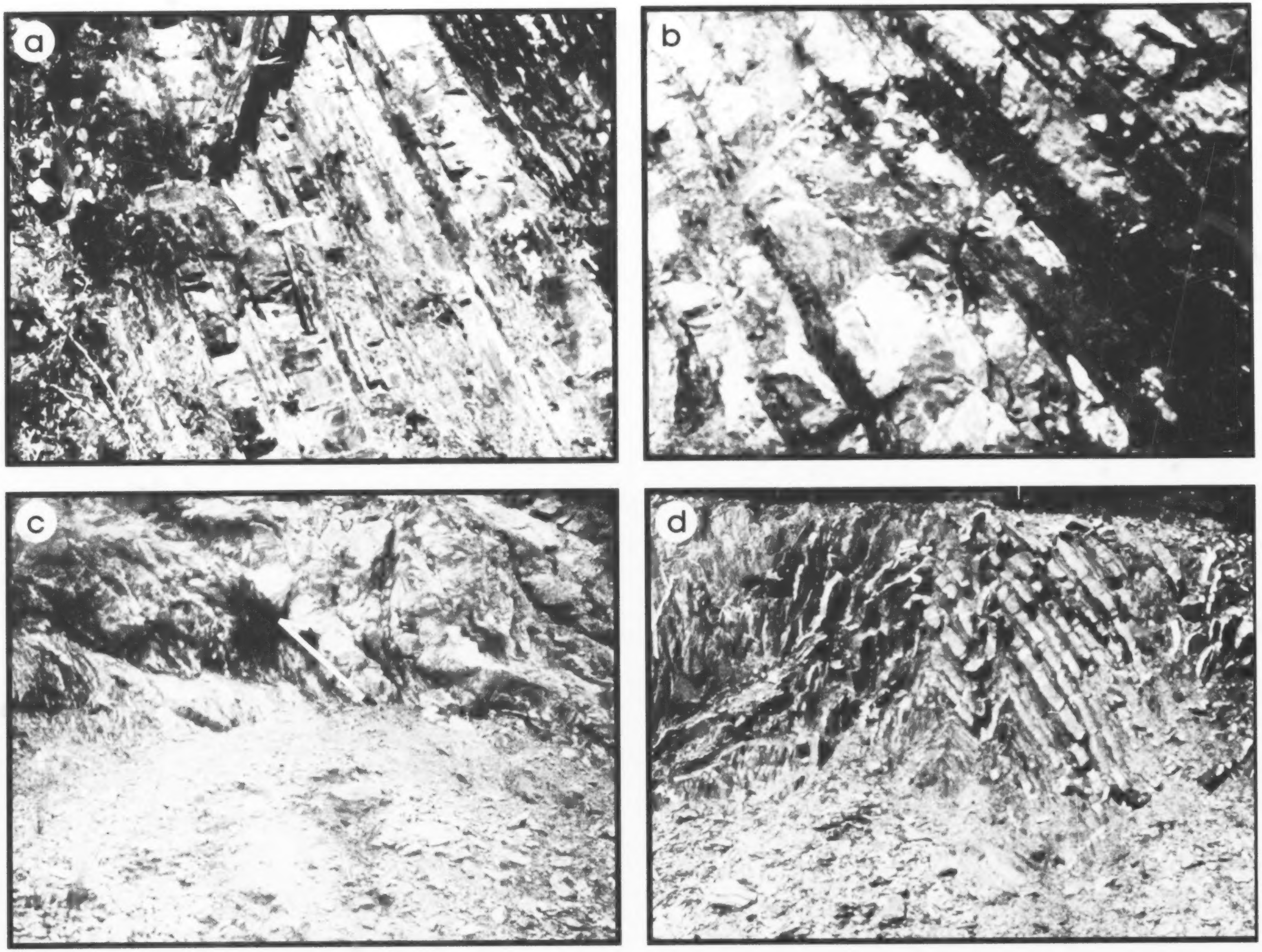
Lithology The Boland Brook Formation mainly consists of dark grey to dark greenish grey, thin-bedded, noncalcareous (rarely weakly calcareous) siltstone, shaly siltstone, and fine-grained sandstone, the relative proportions of which show considerable variation. Bed thickness is greatest in sandstone beds, with the thickest beds consisting of medium- to coarse-grained sandstone and conglomerate. All of these rock types are present in the Sewells Gulch reference section, a uniformly east-dipping series of generally noncalcareous rocks on the east limb of the Coxs Brook Anticline (Figure 1, section A; Figure 3).

The oldest rocks in the Boland Brook Formation crop out at the western end of the Sewells Gulch section, close to the anticlinal axis, and consist of medium- to thick-bedded (up to about 1 m), greenish grey, medium- to coarse-grained, cross-laminated sandstone, grit, fine-grained polymictic conglomerate, and minor thin-bedded, fine- to medium-grained sandstone. Up-section (to the east), these rocks are succeeded by thin-bedded (0.5–4 cm), greenish grey, noncalcareous siltstone, shale, and fine-grained sandstone with local lenses and discontinuous bands of fine-grained, grey lime mudstone. This sequence is in turn overlain by interbedded, cross-laminated sandstone and siltstone that constitute the greater part of the section. The proportion of sandstone beds ranges from less than 10% to greater than 70% (Figure 4a); i.e., thin-bedded shale and siltstone dominate over some short intervals. Bed thickness typically ranges from 4 to 15 cm, with some beds up to 30 cm, and, near Sewells Gulch, a few beds of medium-grained sandstone are 50 to 100 cm thick. Beds of weakly to moderately calcareous siltstone or sandstone become more common east of Sewells Gulch, marking the transition into overlying, typically more calcareous rocks of the Whites Brook Formation (see below). Medium grey, medium- to thick-bedded (exceeding 1 m in places), noncalcareous to weakly calcareous, fine- to coarse-grained sandstone and minor siltstone of the Whites Brook Formation crop out to the east of a 150 m break in exposure above the easternmost outcrop of the Boland Brook Formation.

Boland Brook conglomerates contain lithologically diverse, rounded to subangular clasts of felsic and mafic volcanic rock, fine-grained sedimentary rock, chert, quartz, feldspar, minor calcite and accessory zircon, in a mudstone or siltstone matrix. Lithic clasts, with few exceptions, are unfoliated. Sandstones of the Boldand Brook Formation are typically immature feldspathic lithic arenites, containing poorly to moderately sorted, subrounded to angular grains of quartz, feldspar, rock fragments, minor calcite, and abundant accessory zircon.

Contact relations and thickness The base of the Boland Brook Formation is not exposed in the survey area. However, in the Pat Brook area east of the McKenzie Gulch Fault, conglomerate and sandstone (Pat Brook beds of Carroll 2000) resembling the coarse-grained rocks near the base of Sewells Gulch reference section overlie Caradocian (and older?) chert and mafic volcanic rocks of the Balmoral Group, suggesting that the latter may underlie the Boland Brook Formation in the Squaw Cap area as well. The contact is inferred to be disconformable, as is the case at the Balmoral Group–Matapédia Group contact in the Popelogan area to the east. Although the contact with the overlying Whites Brook Formation is not exposed, it is assumed to be conformable and gradational; where the Whites Brook Formation is absent, e.g., in the Upsalquitch River area, the Boland Brook Formation is conformably overlain by the Pabos Formation (Matapédia Group)(Figures 2 and 3). At the Sewells Gulch reference section, about 1150 m (true thickness) of strata are exposed in continuous outcrop. Based on the interpreted locations of the axis of the Coxs Brook Anticline, and the contact with the overlying Whites Brook Formation, the total thickness of the Boland Brook Formation along Upsalquitch River is probably about 1600 m.

Age The Boland Brook Formation in the Squaw Cap area (mainly from the Sewells Gulch reference section) has yielded a chitinozoan microfauna that has been assigned an early Richmondian (early Ashgillian) age (E. Asselin, written communication). The Boland Brook Formation is equivalent to Caradocian to Ashgillian noncalcareous slate in the Siegas area (the "unnamed unit" of Hamilton-Smith 1970), and, at least in part, to the Caradocian to Ashgillian Madawaska Lake Formation in northeastern


a
b
c
d

Maine (Roy and Mencher 1976). It is lithologically similar to the Garin Formation in the southern Gaspé Peninsula (Malo 1988); the Garin Formation has yielded graptolites ranging from the upper *C. spiniferus* Zone to the *P. manitoulinensis* Zone (late Caradocian to early Ashgillian)(Riva and Malo 1988). A late Middle to Late Ordovician age for the Grog Brook Group was indicated by collections of graptolites, brachiopods, bryozoans and corals from scattered locations in northern New Brunswick (St. Peter 1978).

Whites Brook Formation

The type section of the Whites Brook Formation is on Whites Brook, west of the Squaw Cap area between Restigouche River and Route 17; it extends from the contact with the overlying Pabos Formation (2 km above the confluence with Restigouche River), upstream for a distance of about 10 km to the mouth of Falls Brook. The Whites Brook Formation underlies a large area between the Restigouche and McKenzie Gulch faults, in the central part of the Aroostook–Percé Anticlinorium (St. Peter 1978; Carroll 2000, In preparation). In the Squaw Cap area, the best exposures of the Whites Brook Formation are located on Route 17 at Squaw Cap (Figure 1, section B), on Route 17 at Robinsonville, and on the south side of Restigouche River just west of the confluence with Upsalquitch River (Figure 1, location 3).

Lithology The Whites Brook Formation predominantly consists of light grey to greenish grey, thin- to thick-bedded (approx. 6 cm to 1 m or more), medium- to coarse-grained, typically calcareous sandstone, grit, and minor conglomerate, with thin (2–8 cm) interbeds of dark grey noncalcareous shale and siltstone (Figure 4b). At the Squaw Cap section (Figure 1, section B), the thickest sandstone intervals, up to 10 m, comprise amalgamated turbedite beds. Thin-bedded, dark grey shale normally occurs as thin inter-turbidite layers, but some shale intervals are up to 1 m thick. A secondary facies association in the Whites Brook Formation resembles parts of the underlying Boland Brook Formation and comprises medium grey to medium greenish grey, thin- to medium-bedded (6-30 cm), noncalcareous, fine- to medium-grained sandstone and siltstone, and minor dark grey mudstone. In thin section, coarser-grained lithotypes of the Whites Brook Formation resemble those of the Boland Brook Formation, except for the typically much greater abundance of carbonate in the former. Lithic, feldspathic, calcareous sandstones and conglomerates contain angular to subrounded clasts of unfoliated felsic and mafic volcanic rock, quartz, feldspar, calcite, fine-grained sedimentary rock, chlorite, and accessory zircon. Some of the carbonate clasts have a "porous" internal structure and probably have a biogenic origin.

Paleoenvironment Primary structures and bedforms typical of turbidity current deposits, as described by St. Peter (1978), are much more common in the Whites Brook than in the underlying Boland Brook Formation. These features include load casts, graded beds, parallel and cross-laminations, local convolute laminae, and rip-up clasts of dark grey mudstone concentrated at the base of coarse-grained beds. These sedimentary structures, along with a great lateral variation in thickness,

Figure 4. (a) Thin- to medium-bedded, fine- to medium-grained sandstone and siltstone, Boland Brook Formation on Upsalquitch River (Section A, location 1 in Figure 1). Hammer is 40 cm long. (b) Medium- to thick-bedded, medium- to coarse-grained, noncalcareous to moderately calcareous sandstone with thin interbeds of dark grey noncalcareous shale, Whites Brook Formation at Squaw Cap (Section B, location 2 in Figure 1). Width of section is about 16 m. (c) Sellarsville Fault: disrupted beds of noncalcareous, medium-grained sandstone of the Whites Brook Formation are thrust over (arrow) thin-bedded, strongly sheared, calcareous siltstone and calcilutite of the Pabos Formation (location 3 in Figure 1). Width of section is about 15 m. (d) Tight folding in interbedded calcareous sandstone (light) and calcareous siltstone (dark), Pabos Formation (location 4 in Figure 1). Width of section is about 12 m.

suggest that the Whites Brook Formation records deposition by turbidity currents in a major submarine channel system, compared to a distal (or overbank) submarine fan environment for most of the Boland Brook Formation.

Contact Relations and Thickness The Whites Brook Formation is conformably and gradationally underlain by the Boland Brook Formation, and conformably and gradationally overlain by the Pabos Formation (Matapédia Group). The contact with the Pabos Formation is exposed in a roadcut on Route 17 at Squaw Cap (Figure 1, section B), and is placed at the base of the first bed of dark grey calcareous siltstone, about 15 m west of a 35 m-wide felsic dyke. Although the lower part of the Pabos Formation contains medium- to thick-bedded calcareous to noncalcareous sandstone beds like those in the Whites Brook Formation, the finer-grained lithotypes (dark grey shale and siltstone) in the Pabos are distinctly calcareous, whereas those in the Whites Brook are not. Just west of the confluence of Upsalquitch and Restigouche rivers, the Sellarsville Fault forms the contact between the Whites Brook and Pabos formations. The Sellarsville Fault is a high-angle reverse or thrust fault dipping about 45° to the west (*cf.* Bourque and Lachambre 1980; Lachance 1993), with the Whites Brook Formation in the hanging wall (Figure 4c). Whites Brook rocks are evidently cut out along this fault, as they do not appear on the northern arm of the large bend in the Restigouche River west of Slate Mountain (Figure 1). The thickness of the Whites Brook Formation diminishes greatly northeast of the type area: it is up to 4000 m thick at the Whites Brook type section and 3500 m on Grog Brook, but pinches out to the northeast. On Route 17 north of Coxs Brook, and in the Mill Brook area (Figure 1), up to 500 m of Whites Brook strata may be present, but east of Robinsonville near the Manns Gulch Fault, the Whites Brook Formation is absent and the Pabos Formation rests conformably on the Boland Brook Formation (Figures 1 and 3).

Age Fossil evidence indicates a late Middle to Late Ordovician age for the Grog Brook Group (St. Peter 1978). A chitinozoan fauna from the upper part of the Whites Brook Formation (Figure 1, section B) has been assigned a middle Richmondian (early to middle Ashgillian) age, corresponding to the *D. complanatus* graptolite zone (E. Asselin, written communication). This is consistent with the late Caradocian to early Ashgillian age of graptolites from the Garin Formation (Riva and Malo 1988), which is lithologically similar to the underlying Boland Brook Formation.

Matapédia Group

The Matapédia Group is a widespread and distinctive unit in the Gaspé Peninsula, in western and northwestern New Brunswick and in northeastern Maine, USA, and as such has been the subject of many studies over the past century. Crickmay (1930, 1932) used the term "Matapédia Series" for the slates and limestones exposed in the lower Matapédia Valley, Québec. Alcock (1935) referred to these rocks as the Matapédia Group and correlated them with the White Head Formation (Schuchert and Cooper 1930) in eastern Gaspé. Clarke (1908), Schuchert and Cooper (1930), Cooper and Kindle (1936) and Kindle (1935, 1936) conducted studies of the Pabos and White Head formations in the Gaspé Peninsula, and these formations were included in the Matapédia Group by McGerrigle (1950), Sanschagrin (1963), Skidmore (1965) and Ayrton (1967). The Pabos and White Head formations were redefined, and constituent members of the latter unit were erected following detailed stratigraphic analyses by Lespérance *et al.* (1987) and Malo (1988).

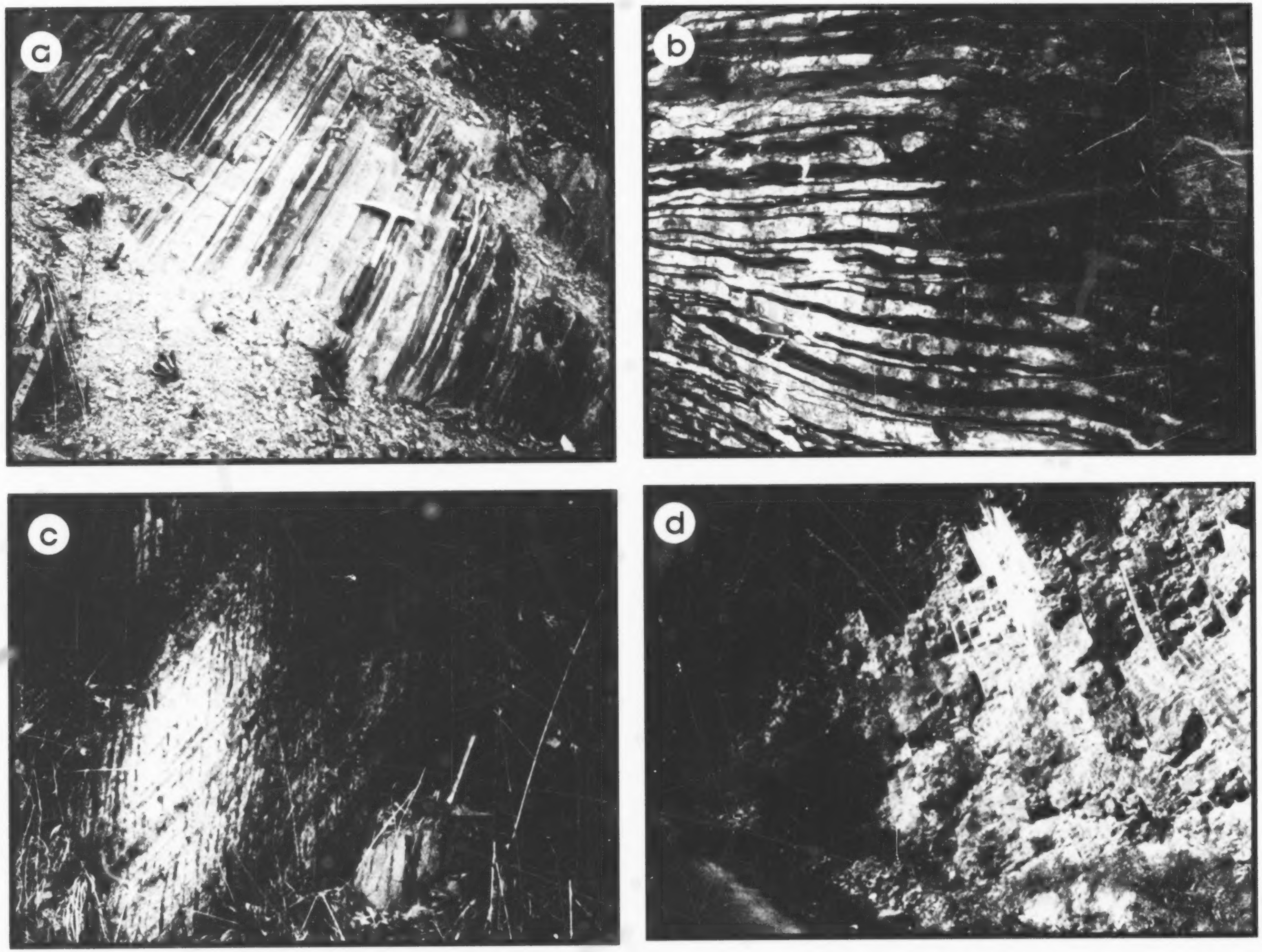
In New Brunswick, Richardson (1859) mapped the rocks on Restigouche River, and Robb (1870, 1872) mapped parts of northwestern New Brunswick, noting the "ribbon" limestones (*i.e.*, Matapédia Group) in the Grand Falls area. Bailey and McInnes (1887, 1889) outlined the distribution of calcareous rocks in northern New Brunswick, but included the "ribbon rock" with other Silurian strata. Pavlides (1966, 1968) introduced the Carys Mills Formation for equivalent rocks in Aroostook County, Maine, and this usage was extended into western New Brunswick by Anderson (1968), Hamilton-Smith (1970, 1972), and St. Peter (1982). St. Peter (1978) delineated the Matapédia Group in northwestern New Brunswick, applying the terminology used in Gaspé, but without the divisions recognized there. Matapédia rocks were mapped in other parts of northwestern New Brunswick by Irrinki and Crouse (1986) and Wilson (1990); subdivisions of the Matapédia, following the Gaspé nomenclature (namely, Pabos and White Head formations) were first described by Wilson (2000a) and Carroll (2000, In preparation). In the Squaw Cap area, Matapédia rocks occur to the west of the Sellarsville Fault, on the western and eastern limbs of the Coxs Brook Anticline, and east of the McKenzie Gulch Fault between Grog Brook and Boland Brook (Figure 1).

Pabos Formation

The Pabos Formation is a mainly terrigenous unit that is transitional between the underlying siliciclastic Grog Brook Group and overlying carbonate rocks of the White Head Formation. It includes two facies associations: (1) a dominant thin-bedded calcareous siltstone facies that resembles the White Head Formation except for the much greater abundance of siliciclastic material, and (2) a locally developed, medium- to thick-bedded sandstone turbidite facies that is lithologically similar to the underlying Whites Brook Formation, except for a much greater carbonate component in the Pabos (especially in the finer-grained rocks). Some of the rocks now assigned to the Pabos Formation, especially those of the sandstone turbidite facies, were considered by St. Peter (1978) to be part of the Grog Brook Group.

The sandstone turbidite facies is typically, but not always, found in the lower part of the unit, overlying the Whites Brook Formation, and is restricted to the east side of the Sellarsville Fault. Like the Whites Brook Formation, it appears to reflect deposition in submarine channels, and passes laterally into the calcareous siltstone facies. For example, beds of sandstone and grit are commonly up to 60 cm thick (and may exceed 1 m) near the mouth of Upsalquitch River, but are much thinner on Route 17 along strike to the south (Figure 1, location 4), and are absent south of Coxs Brook. Similarly, the lower part of the Pabos at section B (Figure 1) is dominated by medium to thick-bedded calcareous sandstone, but on Upsalquitch River, along strike to the southeast, thin-bedded calcareous siltstones overlie the Boland Brook Formation, and coarse-grained rocks are absent (Figure 3). Sandstones and conglomerates are not common in the Pabos section of the Gaspé Peninsula, although they have been reported from the middle part of the Pabos Formation in Honorat Township, and the upper part of the Pabos in the Chandler area (Malo 1988).

Lithology: sandstone turbidite facies The sandstone turbidite facies consists of light to medium grey, medium- to thick-bedded (generally <30 cm, but locally up to 1.5 m), fine- to coarse-grained, moderately to strongly calcareous (rarely noncalcareous) sandstone, grit and minor fine-grained conglomerate, interbedded with varying proportions of darker grey moderately to strongly calcareous siltstone (Figure 4d). All primary sedimentary structures present in the Whites Brook Formation (see above) are also found in this facies of the Pabos. However, the calcareous nature of the finer-grained rocks distinguishes the Pabos from the Whites Brook, and defines the contact between these units on Route 17 (Figure 1, section B; see above). Pabos sandstones, grits, etc. are also typically more calcareous than Whites Brook sandstones, although noncalcareous sandstones have locally been noted in the Pabos, e.g., in the eastern part of section B (Figure 1). Petrographically, the sandstones and conglomerates resemble those in the Whites Brook Formation, i.e., they contain poorly sorted, poorly rounded, grain-supported clasts of quartz, feldspar, calcite, abundant lithic fragments (felsic and mafic volcanic, felsic intrusive, and fine-grained sedimentary rocks), and accessory zircon. Locally, clastic grains are set in a matrix of recrystallized, incipiently sparry


a
b
c
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calcite. The best continuous exposure of the sandstone turbidite facies is on the east bank of Restigouche River, at a location known locally as the Rafting Ground (Figure 1, section C). This section was measured and the lithostratigraphy graphically portrayed by Nowlan (1983).

Lithology: calcareous siltstone facies The calcareous siltstone facies constitutes the upper part of the Pabos Formation east of the Sellarsville Fault, and the entire Pabos section west of the fault. It dominantly consists of dark grey, thin-bedded (0.25–4 cm), moderately to strongly calcareous siltstone and shale (Figure 5a), with minor silty calcilutite (lime mudstone) and thin beds (2–6 cm) of medium to dark grey, fine-grained calcareous sandstone. In places, the fine-grained sandstone occurs as parallel- and/or cross-laminated beds up to 30 cm thick. The calcareous siltstone facies is best exposed in a nearly continuous, 750 m (650 m true thickness) section along Route 134 just west of the Sellarsville Fault (Figure 1, section D). It is proposed that these outcrops be designated a reference section for the Pabos Formation in New Brunswick. The lower contact of the Pabos Formation is not exposed here; however, outcrops just above the Whites Brook contact to the southwest, on the south side of Restigouche River, are very similar to those seen in section D, except that they include minor beds of calcareous sandstone up to 30 cm thick.

Contact relations and thickness As suggested in the above discussion, the upper and lower contacts of the Pabos Formation are conformable and gradational. The contact with the overlying White Head Formation is exposed near the west end of section D (Figure 1), and is defined as the stratigraphic level at which the proportion of (White Head-like) calcilutite and silty calcilutite exceeds that of (Pabos-like) calcareous siltstone and shale. The contact with the underlying Whites Brook Formation at Squaw Cap has been discussed above. On Upsalquitch River, upstream from Robinsonville, the Pabos is juxtaposed against the Boland Brook Formation along the Manns Gulch Fault, and a small splay of the McKenzie Gulch Fault (Figure 1). The apparently conformable contact, located between the two faults, is intruded by felsic dykes.

In the Rafting Ground section (Figure 1, section C), 450 m (about 280 m true thickness) of the sandstone turbidite facies is exposed on the west limb of an anticline whose axis is located at the southeast end of the outcrop. The sandstone turbidite facies is 250–350 m thick in the Squaw Cap area, although, because of lateral facies change along strike to the southeast, the entire Pabos section along Upsalquitch River (up to 350 m) consists of calcareous siltstone. The calcareous siltstone facies is 650 m thick at the Route 134 section west of the Sellarsville Fault (Figure 1, section D).

Age Brachiopods from the Pabos Formation in Gaspé Peninsula are indicative of an Ashgillian age (Lespérance *et al.*, 1987; P.J. Lespérance, in Malo 1979, 1986). Nowlan (1983) reported conodonts of probable late Ashgillian (Gamachian) age in strata on the Restigouche River above Rafting Ground Brook (Figure 1, section

Figure 5. (a) Thin-bedded calcareous siltstone and silty calcilutite (white beds) of the Pabos Formation (Section D, location 5 in Figure 1). Hammer is 40 cm long. (b) "Ribbon-rock" facies of White Head Formation, consisting of thin-bedded, argillaceous limestone or calcilutite (white) and thinner interbeds of dark grey calcareous shale (location 6 in Figure 1). Length of hammer is 45 cm. (c) Thin-bedded silty calcilutite with steep penetrative cleavage, base of White Head Formation (location 7 in Figure 1). Length of hammer is 40 cm. (d) Thin- to medium-bedded calcilutite, White Head Formation (location 8 in Figure 1); this is a relatively clean limestone with no shale interbeds. Truck in background for scale.

C). These rocks were considered by Nowlan (1983) to belong to the Grog Brook Group; however, because the fine-grained as well as the coarse-grained rocks are typically moderately calcareous, the entire section is herein reassigned to the Pabos Formation. Graptolites collected from the same section have been identified as diagnostic of the *Dicellograptus complanatus* Zone of middle Ashgillian age (Riva and Malo 1988).

White Head Formation

The White Head Formation is divided into four members in the Gaspé Peninsula. These are, in ascending order: the Burmingham, Côte de la Surprise, L'Irlande, and Des Jean members (Lespérance *et al.* 1987; Malo 1988). All except the Côte de la Surprise Member dominantly consist of calcilutite or argillaceous limestone. In New Brunswick, the major lithotypes resemble those of the Burmingham and L'Irlande members in the type area, although no such subdivision has been attempted outside of Québec. Internal, locally mappable units of calcareous to noncalcareous shale, slate, and greywacke, reported by Pavlides (1968), Hamilton-Smith (1970; "Middle Slate member"), St. Peter (1978), and Irrinki and Crouse (1986), may correlate with calcareous mudstone of the Côte de la Surprise Member in the type area. St. Peter (1978), Irrinki and Crouse (1986), and Wilson (1990) included rocks of the White Head Formation in an undivided Matapédia Group, and Hamilton-Smith (1970, 1972), Pavlides (1968), and St. Peter (1982) assigned them to the Carys Mills Formation. The White Head Formation was introduced to New Brunswick when the major divisions of the Matapédia Group were recognized by Wilson (2000a) and Carroll (2000, In preparation). The best exposures of the White Head Formation are west of the Sellarsville Fault on Restigouche River and Route 134, and in some roadcuts along Upsalquitch River upstream from the mouth of Grog Brook. Few White Head outcrops have been found in the poorly exposed area between the McKenzie Gulch and Sellarsville faults.

Lithology Regionally, the most distinctive lithotype in the White Head Formation is a white-weathering, dark grey to bluish grey, very fine-grained lime mudstone (calcilutite), regularly interbedded with brown-weathering calcareous shale. The generally uniform thickness of the alternating layers of carbonate and shale, and their resistant and recessive weathering characteristics, respectively, have earned the descriptive term "ribbon rock" for this carbonate facies. In the Squaw Cap area, similar strata are exposed on the east bank of Restigouche River south of Matapédia, Québec, adjacent to a minor fault that has deformed and disrupted the beds (Figure 5b). Ribbon rock is also exposed on the east bank of Upsalquitch River just upstream from the confluence with Grog Brook, where white-weathered calcilutite beds (typically 3–5 cm thick, with some 10–20 cm beds) alternate with thin interbeds of moderately calcareous siltstone.

Most of the White Head section in the survey area, however, consists of thin-bedded silty calcilutite with abundant laminae of very fine-grained calcareous sandstone and minor calcareous siltstone (Figure 5c), with no interbedded calcareous shale. The terrigenous sand–silt component is particularly abundant in the rocks exposed in the Chessers Brook syncline, west of the Sellarsville Fault (e.g., at section E, Figure 1). These rocks correlate with the Burmingham Member of the type area, as they overlie the Pabos Formation and constitute the oldest part of the White Head section. East of the Sellarsville Fault, a similar carbonate facies, but consisting of relatively silt-free limestone in parallel beds up to 10 cm thick, is exposed in the central part of the Val-Melanson anticline (Figure 5d). In both cases, the carbonate rocks are interpreted as amalgamated turbidites unaccompanied by hemipelagic, silty or shaly interbeds.

Between Dawsonville and Squaw Cap, outcrops of the White Head Formation are few in number and generally deeply weathered, but appear to represent a third facies association. The rocks in this area typically consist of fissile, cryptically bedded, shaly calcilutite gradational to calcareous shale, and exhibit a relatively strong slaty cleavage. In some places, thicker beds of more massive, bluish grey calcilutite are present. Minor non-calcareous rocks are also locally observed in the White Head Formation. On Upsalquitch River, just upstream from Grog Brook at the village of Upsalquitch, weakly to moderately calcareous grey shale grades successively into strongly calcareous shale, and calcareous shale alternating with 3–5 cm beds of light grey limestone (i.e., "ribbon rock"). It is possible that these shales correlate with the Côte de la Surprise Member of the type area, but exposure in the area is insufficient to establish their stratigraphic position.

Contact relations and thickness The conformable and gradational contact between the White Head Formation and underlying Pabos Formation is exposed near the western end of section D (Figure 1). In northern New Brunswick, the White Head is typically conformably overlain by the Upsalquitch Formation (Chaleurs Group) (St. Peter 1978; Carroll 2000; Wilson 2000a). In the Squaw Cap area, the contact has not been directly observed, but a prominent topographic lineament coinciding with the approximate location of the contact at the confluence of Boland Brook and Upsalquitch River (Figure 1), suggests that it may be a fault. In the Dawsonville area (Figure 1), the White Head Formation is disconformably overlain by the uppermost Silurian to Lower Devonian Indian Point Formation (Dalhousie Group; see below), and the Upsalquitch Formation is absent. In the southern part of the survey area, the White Head Formation is juxtaposed against the Boland Brook Formation along the McKenzie Gulch Fault.

The thickness of the White Head Formation varies considerably, from 150 m to 2000 m in eastern Gaspé to 4000 m in western Gaspé (Malo 1988). St. Peter (1978) reports a thickness of more than 2800 m for the Matapédia Group, most of which is probably White Head Formation, in the Grand River area of northwestern New Brunswick. In the Squaw Cap area, the White Head Formation is exposed in a continuous 500 m section (approx. 360 m true thickness) just above the Pabos contact on the southeast limb of the Chessers Brook syncline (Figure 1, section E). It is estimated that the total thickness of the White Head Formation in the Chessers Brook syncline is 1200 m.

Age Brachiopods, trilobites, conodonts and graptolites from many locations in Québec, Maine and New Brunswick indicate that the White Head Formation ranges from Ashgillian to Llandoverian (Lespérance *et al.* 1987; Malo 1988; Nowlan 1983; Pavlides 1968; Rickards and Riva 1981; Hamilton-Smith 1970). However, the upper age limit varies from place to place (Wilson 2000a). Chitinozoans obtained from two samples of the White Head Formation in the Dawsonville–Squaw Cap area (Figure 1), including one near the disconformable contact with the overlying Indian Point Formation, indicate a late Richmondian (middle Ashgillian) age (E. Asselin, written communication). In contrast, a dark grey, massive, calcareous siltstone from an outcrop near the Squaw Cap Fault, north of Squaw Cap mountain (Figure 1), also near the contact with the Indian Point Formation, yielded an Aeronian–early Telychian age (Llandovery C_1–C_3; E. Asselin, written communication). This age is at the upper limit of the range reported for the White Head Formation at any location, and, given the large discrepancy between this and the other White Head samples from the same area, suggests that this outcrop should be assigned to the Upsalquitch Formation (see below).

Chaleurs Group

Upsalquitch Formation

The Upsalquitch Formation (St. Peter 1978) underlies the southeastern part of the survey area, south of Val-Melanson and on Upsalquitch River upstream from the confluence with Boland Brook (Figure 1). Upsalquitch rocks have previously been mapped in the Squaw Cap area by Greiner (1974a), who included them in an undivided unit of Early Silurian to Early Devonian rocks, and by Alcock (1941), who outlined the Silurian "Chaleur Bay Series" in this area. However, Alcock's Silurian unit also included some Lower Devonian rocks now included in the Indian Point Formation, whereas some Upsalquitch rocks were assigned by him to the Matapédia Group. St. Peter (1972, 1974) carried out reconnaissance mapping south of Squaw Cap, and successfully distinguished Upsalquitch from Matapédia rocks in that area. In the Popelogan area to the southeast, Wilson (2000a) divided the Upsalquitch Formation into three informal members, the Arsenault Brook member, the dominant White Meadows member, and the Narrows Brook member, in ascending stratigraphic order. All Upsalquitch rocks in the Squaw Cap area resemble those assigned to the White Meadows member by Wilson (2000a).

Lithology The Upsalquitch Formation comprises medium grey to greenish grey, thin-bedded (typically 2–5 cm), bioturbated, slightly micaceous, calcareous siltstone, mudstone and fine-grained sandstone, with minor calcareous shale, calcilutite, and fine-grained calcarenite (sandy limestone). Fine-grained calcareous sandstone and calcarenite are intercalated with darker grey calcareous siltstone, and typically occur as light grey, light brown-weathered, cross-laminated, discontinuous beds, lenses or irregularly spaced laminae, and less commonly as uniform, thin (3–10 cm), cross-laminated or parallel-laminated beds. Upsalquitch lithotypes are described in greater detail by St. Peter (1978) and Wilson (2000a).

In thin section, calcareous siltstones and sandstones contain an average of 60% terrigenous grains (at least 45% quartz, 10–15% feldspar and 1–5% muscovite, opaques, and accessory minerals), and 40% detrital carbonate. Carbonate-rich beds (fine-grained calcarenite to coarse-grained calcilutite) contain, on average, 40% terrigenous grains (25% quartz, 14% feldspar and 1% muscovite), and 60% detrital carbonate grains. Clastic grains are subangular to subrounded, very well sorted, and typically range in size from 0.02 to 0.15 mm (silt to very fine sand), though in some cases grains up to 0.25–0.30 mm were noted. Commonly, bioturbation has produced a patchy mixture of variably calcareous mudstone, siltstone and fine-grained sandstone or calcarenite.

Paleoenvironment Sole markings, and parallel-laminated, current-ripple-laminated or convolute-laminated intervals of rhythmically alternating, strongly and weakly calcareous silty laminae indicate emplacement of much of the unit as small-scale turbid flows (*cf.* Lee and Noble 1977). Commonly, thin to very thin (<1 cm to approx. 4 cm) turbidite beds comprising fine-grained calcarenite or calcareous siltstone are intercalated with thin beds of calcareous shale or siltstone deposited either from suspension or by normal bottom currents. The facies present are comparable to Facies D to G in the submarine fan facies model of Walker and Mutti (1973), and probably reflect deposition in a submarine fan lobe to distal fan or basin plain environment.

Relationship to other units In the Squaw Cap area, the Upsalquitch Formation conformably overlies the White Head Formation, and is disconformably overlain by the Indian Point Formation. The Upsalquitch Formation is equivalent to the Mann Formation in the Rivière Escuminac–Rivière Nouvelle area of southern Gaspé Peninsula. In addition to its lithological similarities to the Upsalquitch, the Mann Formation conformably overlies the White Head Formation, is unconformably overlain by the Indian Point Formation, and has been assigned an early to late Llandoverian age (Bourque *et al.* 1995; Bourque and Lachambre 1980; Malo and Bourque 1993).

Age and thickness Brachiopods in the Upsalquitch Formation indicate an early Llandoverian to early Wenlockian range (Lee and Noble 1977; St. Peter 1978; Irrinki 1990; Wilson 2000a). No additional collections of shelly fossils were made in the survey area, but chitinozoans recovered from one sample collected near Rocky Gulch indicate a Telychian (late Llandoverian) or older age, whereas a sample of presumed Upsalquitch rocks cropping out near Route 17 at Squaw Cap (Figure 1), has yielded an Aeronian–early Telychian (Llandoverian C_1–C_3) age (E. Asselin, written communication).

The thickness of the Upsalquitch Formation is estimated at 1600 m in the Saint-Arthur–Rocky Gulch area. However, minor folds may be more common than presently recognized in this generally poorly exposed area, so this represents a maximum figure. The Upsalquitch Formation is also estimated to be 1600 m thick in the type locality near Upsalquitch Forks to the southeast (Lee and Noble 1977). West of the McKenzie Gulch Fault, the Upsalquitch Formation was almost completely eroded during the Salinic orogeny, except for a small remnant just north of Squaw Cap mountain (see above).

Dalhousie Group

Indian Point Formation

The Indian Point Formation (Schuchert and Dart 1926) constitutes the upper unit of the Chaleurs Group in its type area near Port Daniel in the eastern Gaspé Peninsula (Figure 2). Rocks on the northern limb of the Restigouche Syncline, north of Campbellton, New Brunswick, have also been assigned to the Indian Point Formation (Bourque and Lachambre 1980). In the latter area, near Sellarsville, the Indian Point Formation strikes southwest across the Restigouche River into New Brunswick, where the formation is mapped as such for the first time. In the type area, a Late Silurian (Salinic) hiatus is absent, and the Indian Point constitutes the uppermost unit of a continuous, conformable Chaleurs Group section. However, the Indian Point Formation in the Squaw Cap area is herein assigned to the Dalhousie Group because it disconformably overlies the Upsalquitch Formation (Chaleurs Group), and is conformably overlain by the Archibald Settlement Formation (Dalhousie Group).

Some of the Indian Point rocks in the Flatlands area west of Campbellton are portrayed as Upsalquitch Formation on existing maps (e.g., Davies 1979), apparently following Alcock (1941), who divided Indian Point rocks into a Silurian unit he assigned to the "Chaleur Bay Series", and a younger unit of Lower Devonian rocks. Greiner (1974a) undertook reconnaissance mapping and grouped many rocks in this area into an undifferentiated "Early Silurian to Early Devonian" unit that included strata now variously assigned to the Whites Brook, Pabos, White Head, Upsalquitch and Indian Point formations. No mapping has been carried out in the lower Restigouche River area since that time. The foregoing circumstances, along with a tentative Silurian determination on long-ranging genera of colonial corals in two fossil collections from the Glen Levit area (see below), has led to uncertainty regarding the proper stratigraphic designation of these rocks.

Lithology The Indian Point Formation in New Brunswick is a lithologically diverse unit comprising light to medium grey or greenish grey, rarely dark grey, thin- to thick-bedded, commonly fossiliferous, moderately to strongly calcareous siltstone and fine-grained sandstone, fine-grained calcarenite, and minor biostromal limestone, limestone conglomerate, coarse-grained sandstone, polymictic conglomerate, red siltstone, and mafic volcanic rocks. The most common lithological association consists of thin- to thick-bedded (approx. 5 cm to well over 1 m), light to dark grey, buff or pale-brown weathered, fossiliferous calcareous siltstone or fine-grained sandstone, gradational to fine-grained calcarenite (Figure 6a). Siltstones and fine-grained sandstones are slightly argillaceous and micaceous, and contain well-sorted but poorly rounded grains of silt-sized quartz, minor feldspar, and generally 10–40% detrital calcite. Bedding laminations are defined by small variations in grain size or composition, though some samples are texturally

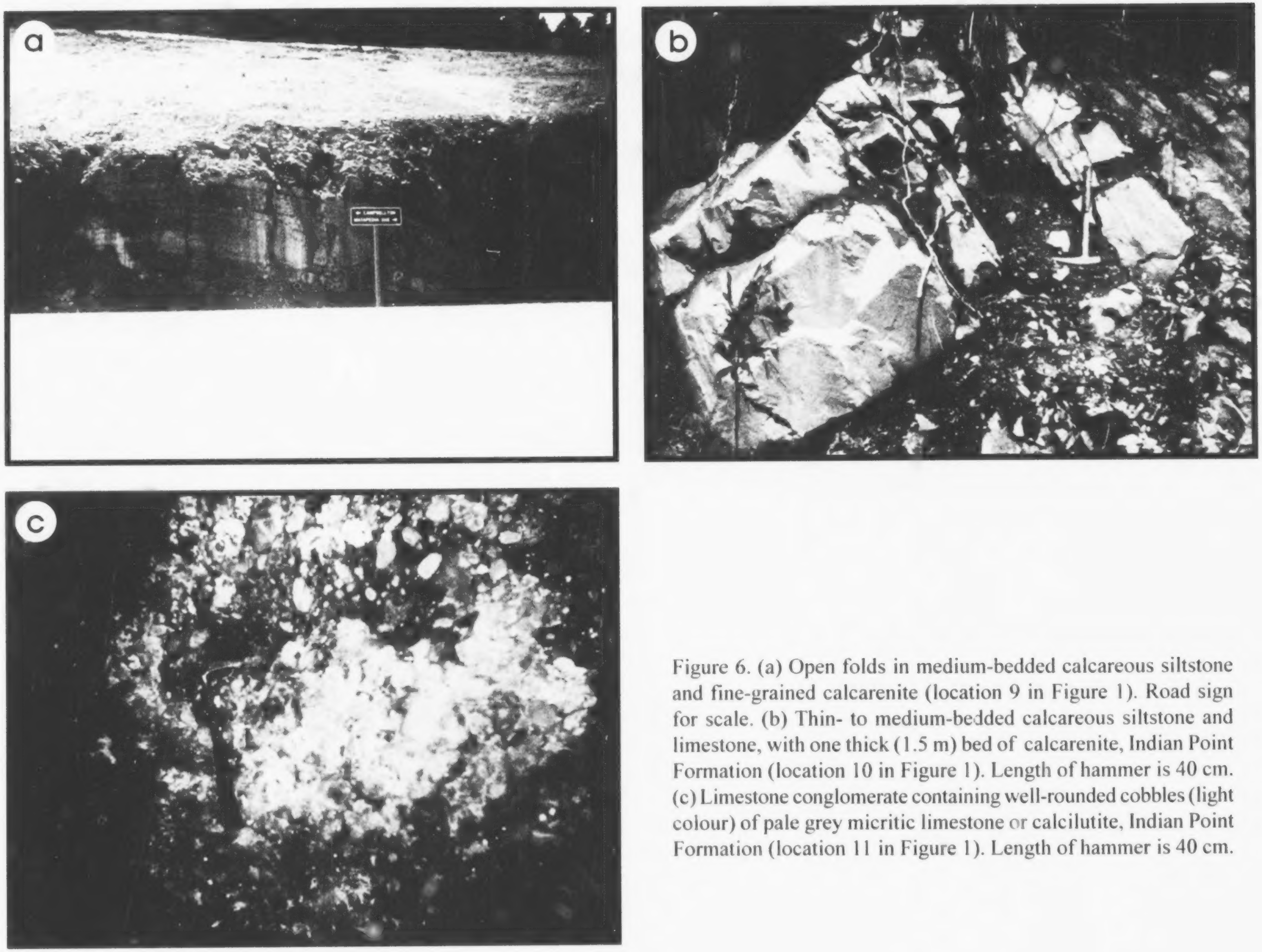

Figure 6. (a) Open folds in medium-bedded calcareous siltstone and fine-grained calcarenite (location 9 in Figure 1). Road sign for scale. (b) Thin- to medium-bedded calcareous siltstone and limestone, with one thick (1.5 m) bed of calcarenite, Indian Point Formation (location 10 in Figure 1). Length of hammer is 40 cm. (c) Limestone conglomerate containing well-rounded cobbles (light colour) of pale grey micritic limestone or calcilutite, Indian Point Formation (location 11 in Figure 1). Length of hammer is 40 cm.

homogenous. Rocks containing greater than 50% detrital carbonate are defined as calcarenites; grain morphology in the latter is the same as in the calcareous siltstones, but terrigenous grains, mostly silt-sized quartz, are subordinate to carbonate (typically 20–40% of the rock). It is very likely that a complete spectrum of terrigenous vs. carbonate components exists, as calcareous siltstones grade into calcarenites. One feature almost all samples share is an abundance of fossil debris, even in rocks containing no intact body fossils. Fragments of brachiopods and bryozoans are most common, with variable quantities of coral, trilobite, crinoid, and ostracode detritus; in rare cases shelly material makes up 25% of the rock, and fragments may be several millimetres in size.

Biostromal limestone, in 20 cm to >1 m thick beds, is locally interbedded with the calcareous siltstones and calcarenites that compose the bulk of the formation. These limestones are typically light grey to light pinkish grey, white-weathering, bioclastic wackestones (Figure 6b). Two or more types of fossils (intact shells and shell fragments) are commonly present, and include brachiopods, bryozoans, corals, trilobites, crinoids, and ostracodes, set in a micritic matrix containing minor quartz, silt and clay. One outcrop, north of Val-Melanson and west of East Branch Christopher Brook, contains a bed of bryozoan-rich framestone with a sparry calcite matrix (biosparite).

Two subsidiary facies associations are locally observed in the Indian Point Formation. The most common comprises thin-bedded (2–5 cm), medium grey, weakly to moderately calcareous siltstone and fine-grained sandstone, with minor fine-grained sandstone in thicker (up to 15–20 cm), parallel-laminated beds. The other is a medium- to thick-bedded (20 cm to >1 m), light grey to bluish grey, buff-brown-weathering, weakly to moderately calcareous, fine- to medium-grained sandstone, with minor coarse-grained sandstone. These beds are typically massive to parallel-laminated, rarely cross-laminated, and commonly contain fossil-rich layers or, locally, carbonized plant debris. On Route 17 at Dawsonville, a fossiliferous, calcareous, coarse-grained lithic sandstone contains well-sorted, moderately rounded clasts of felsic and mafic volcanic rock, quartz, and feldspar.

Minor rock types include limestone conglomerate, polymictic conglomerate, red siltstone, and mafic volcanic rocks. Limestone conglomerate is present only in the Glen Levit area, on Route 17 at Glen Levit, and on small streams flowing west into Kierstead Gulch (Figure 1), where it is interbedded with minor fine-grained, light grey, fossiliferous calcarenite, and reaches a minimum thickness of 150 m. The conglomerate consists of large (up to 8 cm), very well rounded cobbles of pale grey to pink–beige calcilutite, in a fine-grained matrix containing about 60% carbonate grains, up to 20–25% quartz silt, and some fossil debris (Figure 6c). Alcock (1935, p. 51) refers to this conglomerate, interpreting it as a basal Devonian conglomerate between Silurian limestones to the west and Lower Devonian sedimentary and volcanic rocks to the east. He considered the source of the limestone cobbles to be the Matapédia Group, which is confirmed by the identification of Late Ordovician to Early Silurian conodonts in the cobbles (A.D. McCracken, written communication). Alcock (1935) equated this conglomerate with limestone- and volcanic-cobble conglomerate directly overlying the Silurian (Salinic) disconformity in the southern Gaspé Peninsula (*cf.* Bourque and Lachambre 1980). However, all rocks of the Indian Point Formation overlie the Salinic disconformity, so this correlation is regarded as spurious.

Polymictic conglomerate is exposed in scattered outcrops east of the McKenzie Gulch Fault. Clast types include subrounded pebbles of felsic volcanic rock (including porphyritic, devitrified rhyolite and welded vitric-crystal tuff), limestone, basalt, laminated fine-grained sedimentary rock, quartz, feldspar, and calcite. In only one case does the conglomerate crop out at or near the disconformity at the base of the Indian Point Formation, that being the outcrop containing the bryozoan framestone at Val-Melanson, discussed above. Another variety of conglomerate crops out on Route 275 north of Val-Melanson, where a fine-grained volcaniclastic conglomerate consists of abundant basalt clasts in a lithic wacke matrix of quartz, feldspar, rock fragments, calcite, and crinoid fragments.

Red siltstone crops out near the base of the unit east of the McKenzie Gulch Fault, especially in the East Branch Christopher Brook area (Figure 1). The siltstone is thin- to thick-bedded (2 cm–1 m), moderately to strongly calcareous, and typically contains abundant ovoid to lensoid, light green carbonate-rich nodules. Several exposures of mafic volcanic rock are also found in the Indian Point Formation. Dark green, typically amygdaloidal basalt generally occurs as isolated outcrops, except for a series of pavement outcrops on a woods road north of Flatlands, which indicate a minimum width of 50 m at this location. The basalt does not constitute a mappable unit, as outcrops are few and widely scattered, but it may correlate with a thin basalt unit associated with Indian Point rocks on the Québec side of Restigouche River (Bourque and Lachambre 1980).

Paleoenvironment The lithological associations, bedforms, etc., present in the Indian Point Formation indicate deposition in a marine shelf environment below wave base. This is consistent with palynological evidence that points to a fully marine setting (i.e., a predominance of marine taxa), with varying degrees of input from terrestrial sources (E. Burden, written communication). It is also in agreement with an outer shelf to basin environment proposed for deposition of prograding fine-grained siliciclastic rocks that buried the West Point reef tract in the latest Silurian–earliest Devonian (Bourque *et al.* 2000). However, east of the McKenzie Gulch Fault, the presence of polymictic conglomerate, red siltstone, and thick beds of cross-bedded sandstone with plant detritus suggest periods of subaerial to shallow water deposition.

Contact relations and thickness In northern New Brunswick, the Indian Point Formation is conformably overlain by Lower Devonian volcanic rocks of the Archibald Settlement Formation (see below). The contact is exposed on Route 275 between Val-Melanson and Glencoe, where light greenish grey, friable, calcareous mudstone is intruded by mafic dykes displaying crude columnar jointing, and is succeeded to the north by dark green amygdaloidal basalt. East of McLeod Brook, the Sellarsville East Fault forms a tectonic contact between the Indian Point and Archibald Settlement formations. In New Brunswick, the fault is indicated by poor exposures of sheared, phyllitic siltstone and calcareous sandstone mélange accompanied by tight minor folds. The fault is much better exposed on Québec Route 132 on the north side of the Restigouche River, where west-dipping Indian Point beds are juxtaposed against a sequence of interbedded basalt and sedimentary rock, passing into a thick basalt sequence to the east. The Indian Point Formation disconformably overlies the Upsalquitch Formation in the Val-Melanson and Squaw Cap areas. In the Dawsonville area west of Squaw Cap, the Upsalquitch Formation has not been observed and the Indian Point disconformably overlies the White Head Formation.

The thickness of the Indian Point Formation has been estimated at 500 m in the Sellarsville area on the north side of the Restigouche River, and the greatest thickness of the formation (approx. 1500 m) is reported in the Restigouche Syncline north of Campbellton (Bourque and Lachambre 1980). In the Squaw Cap area, the Indian Point is up to 1100 m thick east of the McKenzie Gulch Fault. West of the fault, outcrop is insufficient to determine the amount of fold repetition, although it is clear from the better exposures that meso-scale open folds are probably common (e.g., Figure 6a). It is believed that the thickness here is at least equal to the 500 m estimated for the Sellarsville area across the Restigouche River.

Age Brachiopods indicate a Pridolian to Lockhovian range for the Indian Point Formation in the Gaspé Peninsula (Bourque and Lachambre, 1980). In New Brunswick, previously obtained data pertaining to shelly fossils are limited to four brief references dating back to the 1970's. Corals of possible Late Silurian age, but from long-ranging genera, were recovered from a limestone outcrop on Route 17 southwest of Glen Levit (T. Bolton, written communication), and a Silurian age was assigned to corals and brachiopods from an outcrop on Black Brook, just north of the Sellarsville East Fault and west of the confluence with Kierstead Gulch (A.J. Boucot, written communication)(Figure 1). Greiner (1974a) reports the presence of Devonian brachiopods at Flatlands, and Greiner (1973) refers to probable middle to Late Silurian Pentamerid brachiopods in an outcrop on Route 17 at Dawsonville, not far above the base of the unit. A Late Silurian age is supported by the identification of *Ozarkodina remscheidensis eosteinhornensis* in newly collected samples of limestone (A.D. McCracken, written communication); this species was also reported from the Indian Point Formation in Gaspé by Bourque and Lachambre (1980). It is very unlikely that the Indian Point contains any fossils older than middle to late Pridolian, as it overlies Pridolian fossiliferous limestone of the West Point Formation in the southern Gaspé Peninsula. A Lockhovian upper age limit for the Indian Point Formation is established by a U–Pb (zircon) age of 415.0 ± 0.5 Ma obtained from the Squaw Cap stock (V. McNicoll, written communication), which intrudes the Indian Point Formation between the Manns Gulch and Squaw Cap faults (Figure 1).

Microfossil assemblages confirm a Pridolian to Early Devonian age for the Indian Point Formation: many palynomorphs are Late Silurian–Early Devonian forms, with an early to middle Gedinnian (Lockhovian) age most likely as some of the species present are also found farther east in the Early Devonian Jacquet River Formation (Dalhousie Group)(E. Burden, written communication). A Late Silurian chitinozoan fauna was identified in a sample from near Kierstead Gulch (E. Asselin, written communication), but most samples contained very low abundances of chitinozoans.

Regional correlation As mentioned above, palynological evidence enables the Indian Point Formation to be correlated with the Jacquet River Formation, which crops out farther east, from Jacquet River to the Upsalquitch Forks area. The West Point Formation, which conformably underlies the Indian Point Formation in the Gaspé Peninsula, is a reefal limestone unit equivalent to the LaPlante Formation (Chaleurs Group; Noble 1985) in northeastern New Brunswick; as such, it allows the Indian Point to be correlated with the Upper Silurian to Lower Devonian Budworm City and Free Grant formations of the Chaleurs Group (Walker and McCutcheon 1995), which conformably overlie the LaPlante Formation south and southeast of the Squaw Cap area (Walker and McCutcheon 1990). Lithological elements in common with the Indian Point Formation include calcareous siltstone and sandstone in all units, minor limestone in the Budworm City Formation, and local greyish red slate in the Free Grant Formation. The Upper Silurian to Lower Devonian Greys Gulch Formation, which overlies and interfingers with the Budworm City Formation, contains red siltstone and minor conglomerate and is also contemporaneous with at least part of the Indian Point Formation.

The presence of shallow water deposits east of the McKenzie Gulch Fault suggests the possibility that some of the rocks in this area may belong to the West Point Formation, which also includes some redbeds, and was deposited at, or shortly following, the peak of the Late Silurian regressive (shallowing) phase. In particular, redbeds and conglomerate crop out at the base of the Indian Point north of Val-Melanson, in close proximity to limestone and calcarenite beds that could be analogues of West Point reefs. There is as yet no way to confirm a West Point affiliation for these strata, although conodonts recovered from a bryozoan-rich biostrome (see above) were identified as *Ozarkodina remscheidensis eosteinhornensis*, which ranges from late Ludlovian to Pridolian, i.e., West Point age (Bourque and Lachambre 1980). The possibility remains for the occurrence of isolated West Point patch or pinnacle reefs in the subsurface, above the Salinic disconformity (Figure 3).

Archibald Settlement Formation

At the type locality in the Jacquet River area, the Archibald Settlement Formation (Greiner 1967) consists mainly of felsic volcanic rocks that overlie the Jacquet River Formation (Walker and McCutcheon 1995). In the Squaw Cap area, felsic volcanic rocks are minor, and the sequence dominantly consists of mafic to intermediate flows, breccias and tuffs. Mafic to intermediate volcanic rocks in the Campbellton–Dalhousie area were assigned to the Dalhousie Group by Greiner (1974a, b, c), and include the Dalhousie Mountain andesites, Inch Arran andesites and dacites, Maple Green andesites, and Sugar Loaf dacites of Howard (1926) and Alcock (1935). They are assigned to the Archibald Settlement Formation because of the correlation of the underlying Indian Point sedimentary rocks with the Jacquet River Formation (see above), and the presence of dacites and rhyolites intercalated with the dominant mafic rocks. In the type area, the Archibald Settlement Formation is conformably overlain by the Sunnyside Formation (Walker and McCutcheon 1995), but near Campbellton, east of the survey area, the Sunnyside Formation is absent and Archibald Settlement felsic volcanic rocks are unconformably overlain by the Campbellton Formation (Greiner 1974b, c; Gensel *et al.* 1997).

Lithology The Archibald Settlement Formation mainly consists of dark green, dark grey, and greyish maroon, massive to locally amygdaloidal or sparsely porphyritic mafic flows and related flow breccias. The latter are composed of angular blocks and fragments of basalt or andesite, in a wide range of sizes. They are not interpreted as hyaloclastites, as there is no evidence of submarine conditions, such as pillow lavas, glassy textures, etc. Minor mafic to intermediate pyroclastic rocks (tuffs, agglomerates, and tuff-breccias), coarse basaltic debris flows, and felsic effusive and pyroclastic rocks, are also present in the Archibald Settlement Formation. The debris flows are a very distinctive unit, consisting of large, well-rounded basalt cobbles and boulders (up to 1 m in diameter), in a granulated basaltic matrix. These rocks are best exposed east of the Squaw Cap area, at the Route 11 exit on the east side of Campbellton. The absence of intermixed mud and exotic lithic clasts is inconsistent with a volcanic mud-flow (lahar) origin. It is proposed instead that these rocks were remobilized down on the slope of a large volcanic edifice, with rounding of the boulders caused by mechanical abrasion. Felsic volcanic rocks include pinkish maroon flow-layered rhyolite, and pink to purplish grey lithic crystal tuff containing angular to rounded fragments of pink porphyritic rhyolite up to 15 cm in size, and reddish orange phenocrysts of potassium feldspar up to 1 mm.

Geochemistry Whole-rock analyses of mafic volcanic rocks from the Archibald Settlement Formation were performed at Activation Laboratories Ltd., Ancaster, Ontario, by lithium metaborate/tetraborate fusion ICP and inductively coupled plasma-mass spectrometer (ICP-MS) methods, except for Cr and Sc which were analyzed by instrumental neuton activation analysis. The data reveal close similarities with published analyses of Lower Devonian basalts from the Gaspé Peninsula (Dostal *et al.* 1993)(Table 1). Major element compositions vary from basaltic to dacitic; like the "Dalhousie volcanics" north of the Restigouche River, basalts in the Archibald Settlement Formation are tholeiitic and accompanied by a significant proportion of intermediate rocks. On a Nb/Y vs. Zr/TiO_2 diagram (Figure 7a), subalkaline mafic and intermediate rocks plot along the basalt/andesitic basalt boundary, and in the andesite field, respectively. Mafic and intermediate rocks display sloping, very slightly concave rare-earth-element profiles (Figure 7b), with La/Yb in basalts and andesites averaging 6.79 and 10.36, respectively, compared to La/Yb = 5.29 and 9.41 in corresponding basalts and andesites in Gaspé (Dostal *et al.* 1993), and La/Yb = 7.22 in previously analyzed Dalhousie Group basalts in New Brunswick (Dostal *et al.* 1989). Compared

Table 1. Whole-rock Analyses of Mafic and Intermediate Volcanic Rocks of the Archibald Settlement Formation

	Basalts					Intermediate Rocks			
SAMPLE	0/15F-1011	0/15F-1047	0/15F-1071	0/15F-1076	0/15F-1117	0/15F-1001	0/15F-1015	0/15F-1021	0/15F-1066
(wt%)									
SiO_2	48.22	49.54	49.76	51.21	50.45	63.64	61.36	59.57	56.34
TiO_2	1.56	1.99	1.92	1.49	1.37	0.79	1.02	1.00	1.18
Al_2O_3	17.27	16.25	17.09	17.94	16.05	16.99	16.01	16.78	16.60
Fe_2O_3	10.15	11.19	10.74	8.94	8.46	3.47	5.73	5.27	8.73
MnO	0.21	0.19	0.10	0.07	0.14	0.10	0.11	0.09	0.16
MgO	4.65	4.25	3.69	4.13	7.52	1.95	1.95	1.67	2.07
CaO	9.54	7.85	8.57	4.81	7.81	4.17	4.34	4.94	5.55
Na_2O	3.28	3.78	3.78	4.64	2.73	4.67	4.93	4.85	4.50
K_2O	0.22	1.15	0.76	0.69	0.55	0.89	1.42	1.74	1.21
P_2O_5	0.23	0.32	0.25	0.26	0.22	0.17	0.29	0.26	0.60
LOI	3.50	2.00	2.00	4.66	4.32	3.05	2.46	2.42	1.86
SUM	98.83	98.51	98.66	98.84	99.62	99.89	99.61	98.58	98.80
(ppm)									
Cr	54	30	13	35	272	48	3	3	3
Ni	8	12	1	18	138	22	5	9	1
Co	34	34	28	19	40	17	16	16	16
Sc	30.6	28.2	29.2	23.5	27.2	13.9	14.0	13.3	12.2
V	244	258	318	219	203	80	115	98	83
Cu	40	23	19	22	51	30	49	21	15
Pb	2	11	2	3	2	10	2	10	10
Zn	91	85	81	76	61	44	64	65	108
Rb	1	22	16	15	9	18	34	29	34
Cs	0.1	0.2	0.2	0.8	0.2	0.1	0.4	0.4	1.1
Ba	139	254	224	204	210	692	342	470	275
Sr	468	447	571	631	355	356	466	434	436
Tl	0.03	0.03	0.03	0.03	0.03	0.22	0.12	0.07	0.35
Ga	20	23	22	20	18	16	23	18	25
Ge	1.4	1.2	1.6	1.2	1.3	0.7	1.2	2.8	1.4
Ta	0.39	0.58	0.44	0.47	0.46	0.80	0.82	0.77	1.94
Nb	5.5	8.5	6.9	7.1	6.4	7.5	9.2	8.9	9.9
Hf	3.0	3.7	3.1	3.5	2.6	3.8	5.0	4.8	5.4
Zr	108	142	120	136	111	168	223	216	245
Y	23.3	30.1	25.8	21.2	21.1	13.2	22.6	22.7	35.2
Th	2.01	3.60	2.64	2.85	1.61	6.11	6.10	5.96	2.89
U	0.69	1.22	0.91	1.00	0.50	1.91	2.05	1.91	1.30
La	13.56	21.58	16.01	17.52	12.80	19.17	26.93	29.32	21.13
Ce	29.49	45.12	34.02	37.89	27.13	34.68	51.48	55.99	47.85
Pr	3.79	5.62	4.17	4.66	3.39	3.65	5.65	6.26	6.19
Nd	17.24	24.03	18.42	19.91	14.77	13.51	21.76	23.55	26.84
Sm	4.17	5.62	4.32	4.05	3.40	2.69	4.40	4.77	6.00
Eu	1.54	1.94	1.69	1.43	1.34	0.98	1.35	1.39	2.09
Gd	4.17	5.42	4.57	3.95	3.67	2.56	4.18	4.34	6.03
Tb	0.75	0.93	0.81	0.68	0.67	0.46	0.70	0.74	1.06
Dy	4.46	5.80	4.90	4.06	3.81	2.60	4.02	4.17	6.21
Ho	0.92	1.15	1.00	0.82	0.82	0.53	0.82	0.85	1.26
Er	2.55	3.27	2.74	2.27	2.25	1.50	2.22	2.42	3.47
Tm	0.39	0.51	0.41	0.32	0.35	0.23	0.36	0.35	0.53
Yb	2.34	3.08	2.54	1.98	1.99	1.42	2.13	2.28	3.50
Lu	0.33	0.42	0.37	0.28	0.29	0.20	0.31	0.33	0.50

Notes: Analyses were carried out at Activation Laboratories Ltd., Ancaster, Ontario.
Analytical methods: Cr, Sc by instrumental neutron activation analysis; all others by lithium metaborate/tetraborate fusion ICP and inductively coupled plasma-mass spectrometry (ICP-MS).

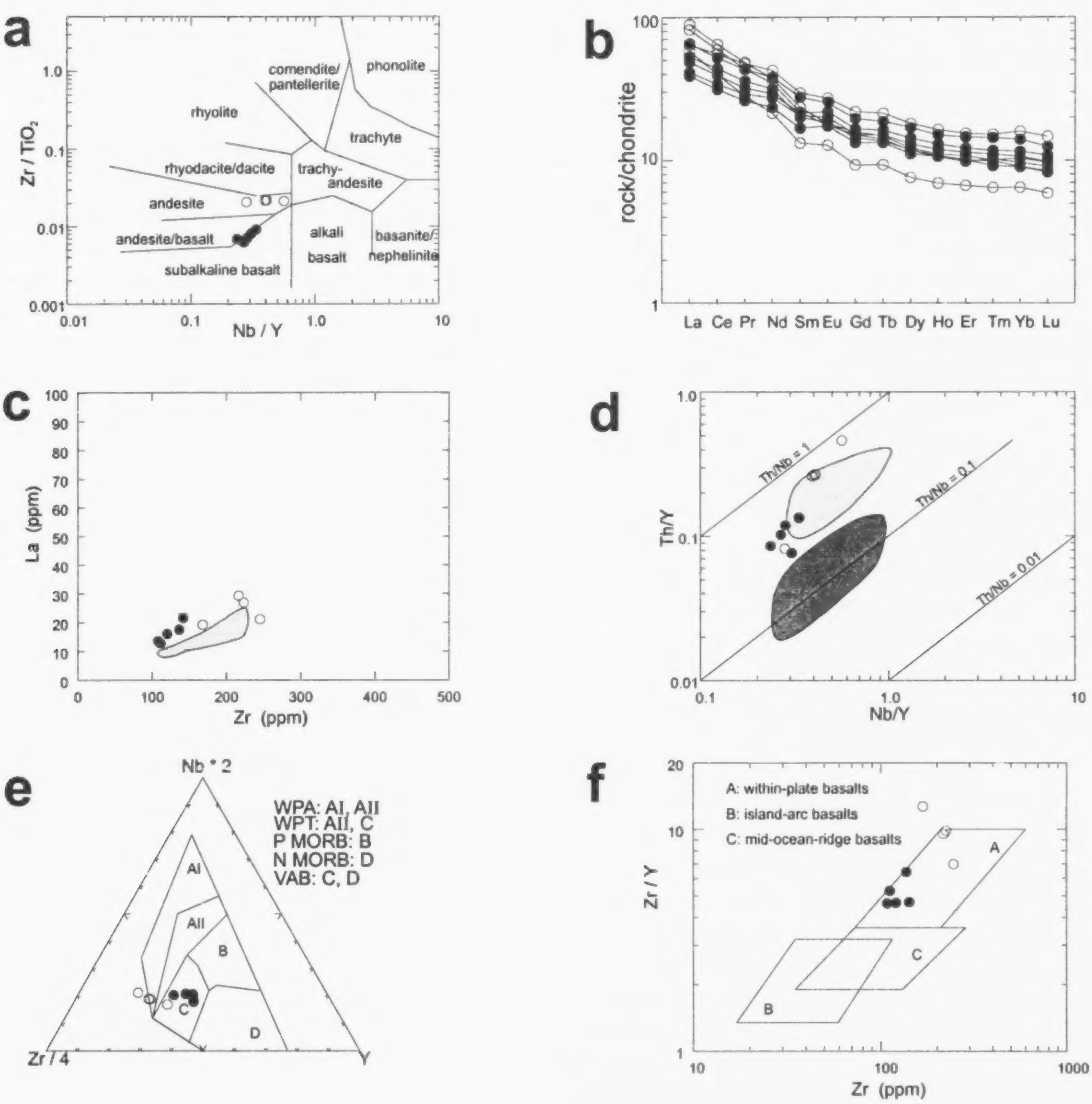

Figure 7. Trace-element variation and discrimination diagrams for mafic and intermediate rocks of the Archibald Settlement Formation. Filled circles (●) are basalts, open circles (○) are andesites. (a) Nb/Y vs. Zr/TiO_2 discrimination diagram of Winchester and Floyd (1977); (b) chondrite-normalized rare-earth-element profiles; normalizing factors are from Sun (1982); (c) Zr vs. La variation diagram. Shaded area outlines the field of Devonian mafic volcanic rocks from the southern Gaspé Peninsula (Dostal *et al*. 1993); (d) Nb/Y vs. Th/Y variation diagram. Dark and light shaded areas outline fields of Devonian basalts and andesites, respectively, from the southern Gaspé Peninsula (Dostal *et al*. 1993); (e) Nb–Zr–Y discrimination diagram of Meschede (1986). Abbreviations: **WPA** – within-plate alkalic basalt; **WPT** – within-plate tholeiitic basalt; **N MORB** – normal mid-ocean-ridge basalt; **P MORB** – plume-influenced mid-ocean-ridge basalt; **VAB** – volcanic-arc basalt; (f) Zr vs. Zr/Y discrimination diagram of Pearce and Norry (1979).

to Devonian mafic rocks in the Gaspé Peninsula (Dostal *et al.* 1993), Archibald Settlement rocks have slightly higher La values (Figure 7c), and slightly higher Th/Nb ratios (Figure 7d). Like other Silurian and Devonian basalts in the northern Appalachians (Dostal *et al.* 1989, 1993; Hon *et al.* 1992), the Archibald Settlement mafic volcanic rocks are typical of within-plate tholeiites (Figure 7e, f).

INTRUSIVE ROCKS

Intrusive rocks include small (about 0.5 to 3.5 km^2) high-level felsic to mafic stocks, dykes and sills that intrude all stratified rock units in the survey area. Stocks of pink to light grey, sparsely porphyritic felsite and microgranite are more resistant than host sedimentary strata and underlie the highest hills in the area, including Squaw Cap, Mann Mountain, and the inappropriately-named Slate Mountain (Figure 1). They also occur as smaller bodies elongated roughly parallel to regional strike, south of Flatlands, east of Kierstead Gulch, south of Squaw Cap, and in the headwaters of Christopher Brook. North of Mann Mountain, two small stocks of light to medium grey, medium-grained, equigranular diorite intrude the Pabos and White Head formations. Gabbroic to diabasic sills (and some dykes) that may be genetically related to the diorite are abundant throughout the Chessers Brook Syncline, and are common in outcrops along Route 134. Felsic dykes/sills are absent west of the Sellarsville Fault, but are more abundant than mafic dykes/sills to the east of the fault. Most of the felsic dykes are pink to orange, feldspar or quartz + feldspar porphyries, but some are aphyric felsites resembling the larger intrusive bodies. In the southern part of the survey area, south of Robinsonville, felsic dykes/sills greatly outnumber their mafic counterparts, and are especially common near interpreted faults (*cf.* St. Peter 1972). There is no significant lithological difference between dykes and sills that intrude older compared to younger sedimentary rocks, suggesting that they are roughly contemporaneous. An Early Devonian age (coeval with Archibald Settlement volcanism?) for the magmatic activity has been established by a U–Pb zircon age of 415.0 ± 0.5 Ma obtained from the Squaw Cap intrusion (V. McNicoll, written communication). Whole-rock analyses of the Squaw Cap and Slate Mountain intrusions are reported by Giggie (1999) and Whalen (1993); they demonstrate that the two bodies are chemically very similar and range in composition from dacite to rhyodacite.

LEFURGEY BROOK LIMESTONE

A very distinctive limestone (*sensu lato*) crops out at two locations south of Flatlands, near the top of a hill east of Lefurgey Brook (location 12 in Figure 1), and in the valley of a small stream about 300 m farther north. At the former location, a series of outcrops and subcrops reveals a progression from a limestone–siltstone breccia (?) at lower elevations, to massive, pale grey, pure limestone near the top of the hill. Chemical analyses show that some samples of this rock are nearly pure calcite, containing about 56% CaO and very low abundances of other major oxides (Table 2). Although the rock is unstratified, the size and distribution of carbonate outcrops point to a limestone thickness of at least several metres. The breccia consists of angular to rounded fragments of limestone in a matrix of dark greenish grey calcareous siltstone and fine-grained calcarenite containing abundant fossil detritus (i.e., a typical Indian Point lithology). The massive limestone is a finely crystalline micrite that typically exhibits laminar, concentric or cup-shaped, apparent growth structures (Figure 8a). However, the rock is unstratified and devoid of fossils and, in thin section, the subtle "growth" laminae, defined by small variations in grain size, are unaccompanied by radial pillars connecting adjacent laminae, as in stromatoporoids. Some rounded to irregular patches of coarser-grained, sparry calcite occur in the fine-grained micrite, along with tiny zircons

Table 2. Chemical Analyses of Lefurgey Brook Limestone (Calcrete)

SAMPLE	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI	TOTAL
0/15E-1474	0.66	0.14	0.12	0.024	0.20	55.64	0.08	0.04	0.006	-0.02	43.40	100.32
0/15E-1474B	0.77	0.19	0.10	0.017	0.21	56.08	0.07	0.03	-0.001	-0.01	42.93	100.39
0/15E-1474C	3.08	0.65	0.24	0.020	0.40	54.64	0.09	0.17	0.027	0.01	40.87	100.19
0/15E-1475	4.18	0.92	0.36	0.018	0.47	52.64	0.19	0.20	0.052	0.01	41.00	100.04

Notes: Analyses were carried out at Activation Laboratories Ltd., Ancaster, Ontario.
Analytical method: lithium metaborate/tetraborate fusion ICP.

(roughly 10 μ in long dimension), very rare silt-sized grains of quartz, and fine-grained, amorphous, unidentified opaque material. The margins of many calcite grains, and clusters of grains, are commonly surrounded by a halo of carbonate containing very fine-grained opaque "dust", forming a mosaic pattern. Some larger, rounded grain clusters seen in thin section resemble ghost fragments or clasts, which may be a manifestation of the (relict) conglomeratic texture observed on the weathered surface of some limestone exposures (Figure 8b). These rocks are identical to other massive limestones, except for the presence of minor dark grey terrigenous material interstitial to rounded, relict clasts.

The Lefurgey Brook limestone manifests many of the characteristics of groundwater calcretes. Calcretes are products of complex hydrochemical processes operating in certain types of arid to semi-arid environments (Wright and Tucker 1991), and are classified according to two main types, pedogenic (vadose) calcretes and groundwater (phreatic) calcretes. Many paleosols are pedogenic calcretes, containing abundant precipitated carbonate forming a durable surface crust or caliche. They are relatively thin, form above the water table, and are characterized by breccia textures, parallel (as opposed to concentric) laminar structures, small-scale karstification features, and relict soil profiles with rootlet impressions (e.g., Ettensohn *et al.* 1988; Goldhammer and Elmore 1984). In contrast, groundwater calcretes form under the water table and are the only calcretes known to exceed 3 m in thickness (Wright and Tucker 1991). Features typical of pedogenic calcretes are absent at the Lefurgey Brook occurrences, but they resemble descriptions of Tertiary–Quaternary phreatic calcretes in central Australia (Arakel and McConchie 1982). Massive groundwater calcretes tend to develop in drainage systems where the water table is close to the surface, especially where fresh groundwater mixes with the saline groundwater of an evaporitic basin close to salt lakes and playas (Arakel and McConchie 1982; Arakel *et al.* 1989; Jacobson *et al.* 1988). Jacobson *et al.* (1988) describe some of the hydrochemical processes resulting in progressive replacement–displacement of alluvium and bedrock by micritic, low-Mg calcite.

Late Carboniferous (?) groundwater calcretes have been documented at several locations in the Gaspé Peninsula by Jutras *et al.* (1999, 2001), who argue that all these occurrences formed at the same time. Although comparisons are hindered by very poor exposure at Lefurgey Brook (especially of contacts), a number of similarities with the Gaspé calcretes (Jutras *et al.* 1999) can be cited: (1) locally, calcretes in the Gaspé Peninsula unconformably overlie the Indian Point Formation (Jutras *et al.* 1999); (2) Gaspé calcretes are overlain by Carboniferous coarse clastic redbeds of the Bonaventure Formation. In New Brunswick, the Bonaventure Formation has probably been eroded in the Lefurgey Brook area, but it crops out farther east near Dalhousie; (3) at Lefurgey Brook, there appears to be a vertical progression similar to that seen in calcretes within the La Coulée Formation (Jutras *et al.* 1999), where the sedimentary protolith grades upward from sedimentary rock with calcrete intraclasts, to calcrete with remnant patches or clasts of sedimentary rock, to massive, clast-free calcrete where all features of the protolith are destroyed; and (4) some Gaspé calcretes contain more than 90% calcite, and rare-earth-element profiles of calcretes

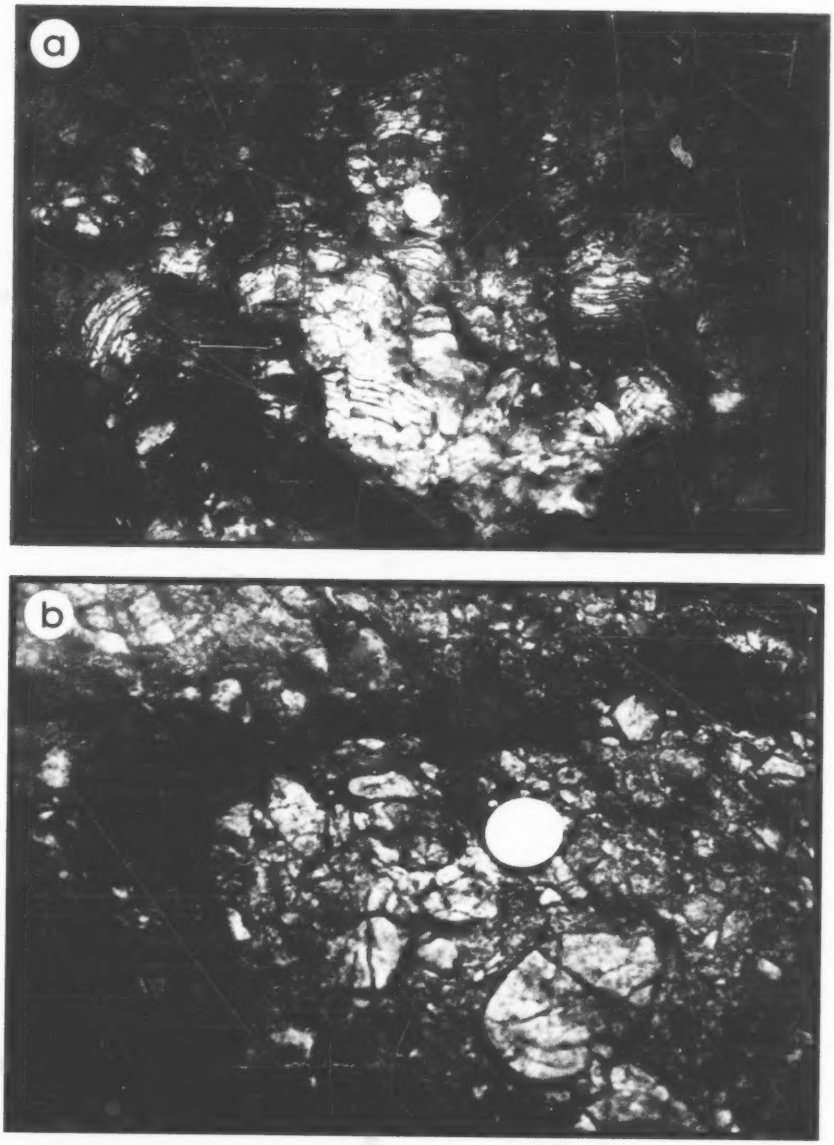

Figure 8. (a) Lefurgey Brook limestone (*sensu lato*), interpreted as a groundwater calcrete, displaying concentric laminar structures in random orientations. This outcrop consists of nearly pure micritic calcite; (b) Lefurgey Brook calcrete, consisting of rounded pebbles and cobbles that have been almost totally replaced by micritic calcite. Both photos taken at location 12 in Figure 1. Coin used for scale is a twenty-five cent piece.

in the La Coulée Formation are very similar to those of the Lefurgey Brook limestone (Figure 9)(Jutras *et al.* 1999; Jutras, written communication). In spite of this, definitive proof of a groundwater origin will depend on fluid inclusion and stable isotope studies to determine the influence of meteoric water in the formation of this rock.

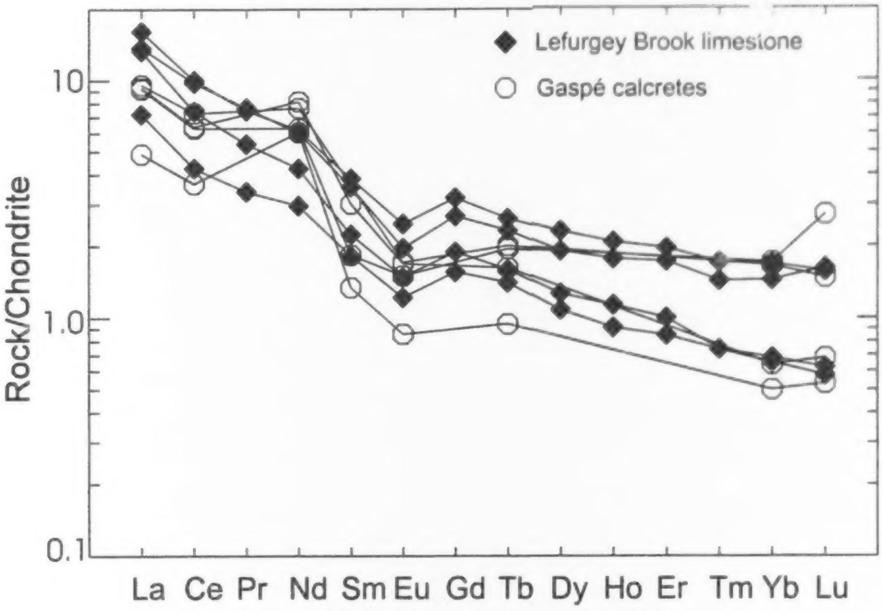

Figure 9. Chondrite-normalized rare-earth-element profiles of Lefurgey Brook limestone compared to calcretes from the Gaspé Peninsula (Jutras *et al.* 1999 and written communication). Normalizing factors are from Sun (1982).

STRUCTURAL GEOLOGY

Folds

Upper Ordovician to Lower Silurian rocks below the Salinic disconformity are thrown into close to tight folds with moderate to steep dips typically to the northwest and southeast, whereas above the disconformity, Upper Silurian to Lower Devonian strata exhibit open folds with shallow to moderate dips ranging from west to north to east. The intensity of axial planar cleavage varies widely; in the Grog Brook and Matapédia groups and Upsalquitch Formation, a weakly to moderately developed penetrative cleavage is the norm, but some rocks display only a close-spaced fracture cleavage, whereas in others a strong penetrative fabric is locally present (e.g., Figure 5c). In the Indian Point Formation, in contrast, only a nonpenetrative fracture cleavage is normally developed. In order to determine if there are systematic structural changes from west to east across major faults, the study area has been divided into three domains, and the corresponding rock structural data into three populations. The three domains represent the areas west of the Sellarsville Fault (domain 1), between the Sellarville and McKenzie Gulch faults (domain 2), and east of the McKenzie Gulch Fault (domain 3).

The main structural elements in the respective domains are the Chessers Brook Syncline (domain 1), the Coxs Brook Anticline and Restigouche Syncline (domain 2), and the Val-Melanson Anticline (domain 3). A stereographic plot of 141 poles to bedding in domain 1, west of the Sellarsville Fault, shows that the points lie on a poorly defined girdle, with a majority of poles associated with northwesterly dips (Figure 10a). The pole to this girdle indicates an average fold plunge of 14° to the southwest. A stereographic plot

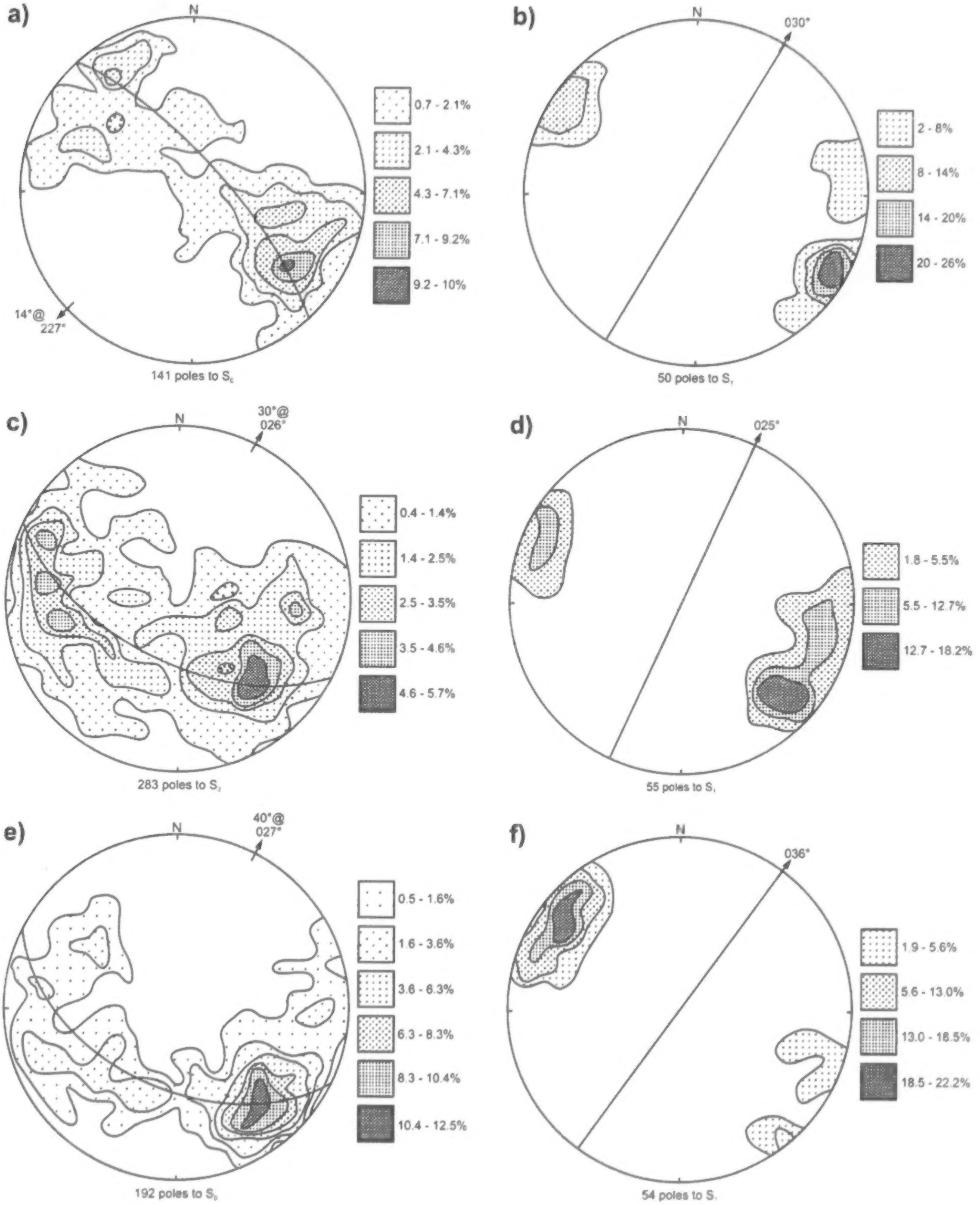

Figure 10. (a) (c) and (e) Contoured plots of poles to bedding in domains 1 to 3, corresponding to the areas west of the Sellarsville Fault, between the Sellarsville and McKenzie Gulch Fault, and east of the McKenzie Gulch Fault, respectively. (b) (d) and (f) Contoured plots of poles to cleavage in domains 1 to 3, respectively.

of 50 poles to cleavage in domain 1 illustrates an average axial surface trend of 030° (Figure 10b); a majority of the dips are to the northwest, suggesting slight, southeast-vergent fold asymmetry, consistent with the predominant northwesterly dips on bedding surfaces. In domain 2, a plot of 283 poles to bedding shows a significant data scatter (Figure 10c); a crudely defined girdle suggests typical fold plunges of about 30° to the north-northeast (026°), which would represent the plunge of the Restigouche Syncline. Again, northwesterly dips predominate. A plot of 55 poles to cleavage produces a pattern very similar to that in domain 1, with an average axial trend of 025° and southeasterly asymmetry (Figure 10d). A stereographic plot of 192 poles to bedding in domain 3 defines a girdle closely resembling that in domain 2, as the pole to the girdle indicates average fold plunges of 40° to the north-northeast (027°) and the point maximum in the southeast quadrant suggests southeast-verging asymmetry (Figure 10e). However, a plot of 54 poles to cleavage illustrates a predominance of steep southeasterly dips (Figure 10f), inconsistent with southeast vergence. These apparently conflicting data could be explained by slight northwest-vergent asymmetry of parasitic folds on the west limb of a large-scale anticline. The large scatter in poles to bedding in all domains may be related to rotation of bedding in proximity to major faults, as shown by the variable orientation of fold axes (Figure 1).

Faults

The Squaw Cap area is transected by several faults that displace units of all ages and display normal, reverse, or strike-slip motion. The Sellarsville Fault (Figure 1, 4c) is a high-angle reverse fault or brittle thrust with the upthrown side or hanging wall to the west (Figure 3). The Sellarsville thrust was mapped in Québec by Bourque and Lachambre (1980) and Lachance (1993), and has been interpreted as an Acadian, post-Middle Devonian structure synchronous with initiation of basement strike-slip faulting (Malo and Bourque 1993; Malo and Kirkwood 1995). The Sellarsville East Fault is a splay of the Sellarsville Fault and has a similar sense of movement. The Squaw Cap Fault (Figure 1) is a dextral strike-slip fault that displaces the Sellarsville Fault and offsets the axis of the Coxs Brook Anticline by 1600–1800 m.

The McKenzie Gulch Fault juxtaposes Grog Brook rocks to the west against Matapédia rocks to the east and, therefore, can be assumed to have some component of vertical motion involving relative uplift to the west (Figure 3). Some sinistral offset of the Upsalquitch Formation is noted on the McKenzie Gulch Fault along Christopher Brook, but most movement probably involved normal downthrow to the east. The Manns Gulch Fault, a splay of the McKenzie Gulch Fault, is evidently the site of 1000–1500 m of sinistral displacement based on offset of the Pabos and Upsalquitch formations. If the McKenzie Gulch Fault were the locus of synsedimentary normal movement, like Late Silurian basin-parallel faults described by Malo and Kirkwood (1995) in the Gaspé Peninsula, this may explain thickening of the Indian Point Formation from 500 m to 1100 m across the fault, as well as the occurrences of conglomerate east of the fault. The chronological sequence of faulting thus implied by these relationships consists of Late Silurian normal faults (McKenzie Gulch), followed by Middle Devonian (or later) reverse faults (Sellarsville and Sellarsville East faults) and, finally, dextral strike-slip movement (Squaw Cap Fault).

DISCUSSION

Tectonic Evolution

Pre-Late Ordovician basement rocks are not exposed in the Squaw Cap area, although elsewhere the Honorat (equivalent to the Grog Brook Group) and Matapédia groups are observed to unconformably overlie Middle to Upper Ordovician rocks of the Dunnage Zone, including the Mictaw Group in the Gaspé Peninsula (Malo and Bourque 1993; Tremblay *et al.* 1993) and the Balmoral and Fournier groups in northern New Brunswick (van Staal *et al.* 1998)(Figure 2). This Ordovician unconformity has been related to uplift caused by collision of the Popelogan arc with Laurentia in the Caradocian (van Staal *et al.* 1991; van Staal *et al.* 1998). During the Ashgillian and Early Silurian, rocks of the Grog Brook and Matapédia groups and Upsalquitch Formation were deposited in a fore-arc setting with respect to northwest-directed subduction of the Tetagouche back-arc basin (van Staal and de Roo 1995). Basin infilling culminated in the Late Silurian with deposition of shallow-water reef tracts and local redbeds and conglomerates, coinciding with the Salinic uplift.

The Late Silurian–Early Devonian sedimentary and magmatic history of the Gaspé Belt was markedly influenced by the Salinic orogeny. The clearest example of the contrasting tectonosedimentary regimes that existed in the Gaspé Belt at this time is the presence of a Late Silurian erosional disconformity or angular unconformity in some parts of the Chaleur Bay Synclinorium (e.g., Wilson 2000b; Bourque and Lachambre 1980) while continuous sedimentation was recorded in the southeastern parts of this belt, both in Gaspé and New Brunswick (e.g., Walker and McCutcheon 1995; Bourque *et al.* 2000)(Figure 2). Different scenarios have been invoked to explain the sequence of sedimentation and volcanism, uplift and subsidence that occurred in the northern Appalachians during this time. Dostal *et al.* (1993) concluded that Siluro-Devonian volcanic rocks in the Gaspé Peninsula were erupted in a northwest–southeast-trending rift zone that developed during dextral transpression in the Québec Reentrant; the Salinic disturbance, in this model, was produced by thermal uplift associated with rifting. On the other hand, van Staal and de Roo (1995) and Cawood *et al.* (1995) present evidence in support of a delamination mechanism to explain uplift caused by rebound of delaminated continental crust in the Late Silurian, followed by magmatism related to asthenospheric upwelling, and extensional collapse of the elevated orogen in the Early Devonian. Delamination, according to van Staal and de Roo (1995), occurred in the latter stages of sinistral oblique collision, which may explain apparent sinistral offset on the McKenzie Gulch Fault. Malo and Kirkwood (1995) associated Late Silurian synsedimentary normal faults with Salinic tectonism reflected by local thermal uplift, intraplate magmatism and extensional collapse. Extensional collapse in the Early Devonian is likely responsible for the Lockhovian subsidence/transgression documented by Malo and Bourque (1993) and Bourque *et al.* (2000), and characterized by deposition of fully marine sedimentary rocks of the Indian Point and Jacquet River formations, for example. Middle Devonian dextral strike-slip faulting, and northeast-trending thrust/reverse faults, have been related to a transpressive regime during Acadian oblique convergence (Malo and Kirkwood 1995).

Salinic uplift west of the McKenzie Gulch fault is supported by near-complete erosion of the Upsalquitch Formation, and an increase in thickness of the Indian Point Formation east of the fault (Figure 3). Furthermore, the dramatic thinning of the Whites Brook Formation east of the Sellarsville Fault suggests that the area between the Sellarsville and McKenzie Gulch faults may have constituted a structural basement high at a much earlier time, supporting an earlier proposal by Nowlan (1983). A significant decrease in burial depth east of the Sellarsville Fault is indicated by a conodont colour alteration index (CAI) of 1 to 1.5 in rocks of the lower Pabos Formation at section C (Figure 1), compared to CAIs of 4 to 5 in rocks of the upper Pabos Formation at section D (Figure 1) west of the fault (Nowlan 1983). In the Middle Devonian, the latter, more deeply buried section was thrust over slightly older rocks to the east, which display only slight thermal alteration. This is consistent with illite crystallinity studies, used to assess burial history up to low metamorphic grades, which indicate a transition to higher values (representing lower metamorphic grade) to the east of a line coinciding with the Sellarsville Fault (Duba and Williams-Jones 1983).

Thermal Maturity and Hydrocarbon Potential

Vitrinite reflectance data show that R_o values range from 2.5% in dark grey shale beds of the Whites Brook Formation at the community of Squaw Cap, to 1.8% in the La Vieille Formation south of Campbellton (east of the study area) to 0.74% in the Indian Point Formation at Glen Levit (R. Bertrand, written communication)(Figure 1). The latter corresponds to the beginning of the oil window (i.e., the temperature at which hydrocarbon generation begins), whereas the more mature La Vieille sample falls in the gas condensate to dry gas zone. Thermal alteration studies carried out on a suite of Indian Point samples have revealed that most are characterized by a thermal alteration index (T.A.I.) of 2.9 to 3.1 (gas condensate to dry gas) but that one sample, collected 3 km west of the Glen Levit location (see above) yielded a T.A.I. of <2.3, well within the oil window (E. Burden, written communication). Colour alteration indices of conodonts recovered from Indian Point samples range from 1.5 to 2 (Figure 1; A.D. McCracken, written communication).

Since 1836, more than 80 oil seeps have been reported and minor hydrocarbons produced in the eastern Gaspé Peninsula (Lavoie and Bourque 2001). Furthermore, recent drilling by Junex Inc. has identified a 500 MMcf/80 acre gas field in fractured Devonian limestone in the northeastern part of the peninsula (Lavoie and Bourque 2001). The oil seeps and limited oil production are associated with the Lower Devonian Upper Gaspé Limestones and Gaspé Sandstones (Lavoie *et al.* 2001; Lavoie and Bourque 2001); gaseous hydrocarbons have been identified in the Late Silurian West Point Formation (Bourque *et al.* 2001), and good source rock intervals have been delineated in the Lower Devonian York River and Indian Point formations (Bertrand and Malo 2001). Much of the Siluro-Devonian succession in northeastern Gaspé, coinciding with the location of hydrocarbon occurrences, lies within the oil window at surface (Bertrand and Malo 2001). Thermal maturity as low as the oil window in two samples of the Indian Point Formation in the Squaw Cap area, therefore, suggest potential for strata in the gas condensate to dry gas zones in the subsurface.

Reflectance and T.A.I. values of 0.7% and 2.3, respectively, and conodont colour alteration indices of 1.5 to 2 correspond to paleotemperatures of about 80°–100° (e.g., Williams *et al.* 1998). Assuming a normal geothermal gradient of 25° to 30° C per km, a burial depth of 2.5 to 3.5 km is most likely. If the Lefurgey Brook "limestone" is equivalent to the calcretes documented in Gaspé, which at least locally occur near the base of the Carboniferous section (Jutras *et al.* 1999), then the thickness of eroded Permo-Carboniferous strata in the Squaw Cap area would be approximately equal to original depth of burial. Interestingly, the thickness of original Carboniferous to Permian sediment cover removed by erosion, based on apatite fission-track analysis, is estimated by Ryan *et al.* (1991) to be up to 3 km, and by Ryan and Zentilli (1993) to be up to 4 km, which compares well with burial depths based on thermal maturity. Higher thermal maturity indices in many of the analyzed samples (Figure 1) may be related to magmatic activity associated with felsitic intrusions or Archibald Settlement volcanism, and east of the McKenzie Gulch Fault, to greater depth of burial.

SUMMARY

The Squaw Cap area is underlain by Middle Paleozoic sedimentary and minor volcanic rocks that can be divided into two conformable successions separated by a Late Silurian (Salinic) erosional disconformity. The lower succession comprises a fore-arc, deep basin sequence of mainly noncalcareous turbidites of the Caradocian–Ashgillian Grog Brook Group, overlain by mainly calcareous turbidites of the Ashgillian to

Llandoverian Matapédia Group, and by continental slope deposits of the lower to upper Llandoverian Upsalquitch Formation (Chaleurs Group). The upper succession consists of shallow marine calcareous sedimentary rocks of the upper Silurian to Lower Devonian Indian Point Formation (Dalhousie Group) and overlying mafic, intermediate, and minor felsic volcanic rocks of the Lower Devonian Archibald Settlement Formation (Dalhousie Group).

The Grog Brook Group has been divided into the Boland Brook Formation and overlying Whites Brook Formation. The Boland Brook Formation mainly consists of dark grey, thin-bedded, noncalcareous mudstone, siltstone and fine-grained sandstone, whereas the Whites Brook Formation is dominantly composed of medium grey, thin- to thick-bedded, calcareous sandstone with thin interbeds of dark grey noncalcareous shale, and local greenish grey, thin- to medium-bedded, noncalcareous, fine- to medium-grained sandstone and siltstone. The Matapédia Group is divided into the Pabos Formation and overlying White Head Formation. The Pabos Formation includes a locally developed basal sequence that is transitional with the underlying Whites Brook Formation, consisting of medium grey, medium-bedded calcareous sandstone and interbedded calcareous siltstone and minor calcilutite, and a dominant upper sequence of dark grey, thin-bedded calcareous siltstone, silty calcilutite and minor fine-grained sandstone. The White Head Formation comprises medium to dark grey, thin-bedded calcilutite and silty calcilutite, locally intercalated with thin beds of dark grey calcareous shale, and minor thin sandy laminae. The Upsalquitch Formation is composed mainly of medium grey, thin-bedded calcareous siltstone and fine-grained sandstone. West of the McKenzie Gulch Fault, the Upsalquitch Formation is thin to absent as a result of Salinic uplift and erosion.

The Indian Point Formation comprises medium grey to greenish grey, thin- to thick-bedded, locally fossiliferous, calcareous siltstone, fine-grained sandstone, calcarenite, and minor limestone, conglomerate, red siltstone, and mafic volcanic rocks. East of the McKenzie Gulch Fault, the Indian Point Formation thickens considerably and contains some thick beds of polymictic conglomerate, suggesting that the McKenzie Gulch was a synsedimentary normal fault in the Late Silurian–Early Devonian. Thermal maturity, as determined by vitrinite reflectance and thermal alteration studies on palynomorphs, is variable in the Indian Point Formation, but two samples west of the McKenzie Gulch Fault fall within the oil window. Strata of similar age and lithology in the Gaspé Peninsula are known to contain hydrocarbons. The Indian Point Formation is conformably overlain by the Archibald Settlement Formation, consisting of mafic to intermediate flows and flow breccias of within-plate tholeiitic affinity, and minor felsic flows and tuffs.

A very pure unstratified limestone, tentatively identified as a groundwater calcrete based on similarity to calcretes documented in the Gaspé Peninsula, is associated with the Indian Point Formation near Flatlands. This calcrete would appear to have formed in an arid to semi-arid subaerial environment, sometime between the Middle Devonian and Late Carboniferous.

The effects of Salinic tectonism are manifested in uplift and erosion. Acadian orogenic events that postdate the Early Devonian have produced open to close folds with northeast-trending axes; moderate, and weak to very weak axial planar cleavage is developed in the older and younger rock sequences, respectively. West of the Sellarsville Fault, the Chessers Brook Syncline plunges at a small angle to the southwest, whereas east of the fault, the Coxs Brook Anticline, Restigouche Syncline, and Val-Melanson Anticline plunge to the northeast at angles of 30–40°. The McKenzie Gulch Fault, along which normal and minor sinistral movement has occurred, is postdated by the Sellarsville Fault, a reverse fault of probable Middle Devonian age, along which older rocks to the west have been emplaced over younger rocks to the east. The Sellarsville Fault is offset by the dextral strike-slip Squaw Cap Fault.

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REFERENCES

Alcock, F.J. 1935. Geology of Chaleur Bay region. Geological Survey of Canada, Memoir 183, 146 p.

Alcock, F.J. 1941. Jacquet River and Tetagouche River map-areas, New Brunswick. Geological Survey of Canada, Memoir 227, 46 p.

Anderson, F.D. 1968. Woodstock, Millville and Coldstream map-areas, Carleton and York counties, New Brunswick. Geological Survey of Canada, Memoir 353, 69 p.

Arakel, A.V. and McConchie, D. 1982. Classification and genesis of calcrete and gypsite lithofacies in paleodrainage systems of inland Australia and their relationship to carnotite mineralization. Journal of Sedimentary Petrology, **52**: 1149–1170.

Arakel, A.A., Jacobson, G., Salehi, M., and Hill, C.M. 1989. Silicification of calcrete in paleodrainage basins of the Australian arid zone. Australian Journal of Earth Sciences, **36**: 73–89.

Ayrton, W.G. 1967. Chandler–Port-Daniel area, Bonaventure and Gaspé-South counties. Québec Department of Natural Resources, Geological Report 120, 91 p.

Bailey, L.W. and McInnes, W. 1887. Report on explorations in portions of the counties of Victoria, Northumberland and Restigouche, New Brunswick. Geological Survey of Canada, Annual Report for 1886, Part N, 19 p.

Bailey, L.W. and McInnes, W. 1889. Report on explorations and surveys in portions of northern New Brunswick, and adjacent areas in Québec, and in Maine, U.S. Geological Survey of Canada, Annual Report for 1887–88, Vol. 3, Part M, 52 p.

Bertrand, R. and Malo, M. 2001. Source rock analysis, thermal maturation and hydrocarbon generation in the Siluro-Devonian rocks of the Gaspé Belt basin, Canada. Bulletin of Canadian Petroleum Geology, **49**: 238–261.

Boucot, A.J., Field, M.T., Fletcher, R., Forbes, W.H., Naylor, R.S. and Pavlides, L. 1964. Reconnaissance bedrock geology of the Presque Isle Quadrangle, Maine. Maine Geological Survey, Quadrangle Mapping Series No. 2, 123 p.

Bourque, P.-A. and Lachambre, G. 1980. Stratigraphie du Silurien et du Dévonien basal du Sud de la Gaspésie, Québec. Ministère de l'Énergie et des Ressources Québec, ES-30, 123 p.

Bourque, P.-A., Brisebois, D. and Malo, M. 1995. Gaspé Belt. *In* Chapter 4 of Geology of the Appalachian–Caledonian Orogen in Canada and Greenland. *Edited by* H. Williams. Geological Survey of Canada, Geology of Canada, no. 6, pp. 316–351.

Bourque, P.-A., Malo, M., and Kirkwood, D. 2000. Paleogeography and tectono-sedimentary history at the margin of Laurentia during Silurian to earliest Devonian time: the Gaspé Belt, Québec. Geological Society of America Bulletin, **112**: 4–20.

BOURQUE, P.-A., SAVARD, M.M., CHI, G., and DANSEREAU, P. 2001. Diagenesis and porosity evolution of the Upper Silurian–lowermost Devonian West Point reef limestone, eastern Gaspé Belt, Québec Appalachians. Bulletin of Canadian Petroleum Geology, **49**: 299–326.

BURK, C.F. 1964. Silurian stratigraphy of Gaspé Peninsula, Québec. American Association of Petroleum Geologists Bulletin, **48**: 437–464.

CARROLL, J.I. 2000. Geology and geophysics of the east half of the Kedgwick map area (NTS 21 O/11 east), northern New Brunswick. *In* Current Research 1999. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resources Report 2000-4, pp. 1–16.

CARROLL, J.I. In preparation. Geology of the Menneval area (NTS 21 O/14), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate.

CAWOOD, P.A., VAN GOOL, J.A.M., and DUNNING, G.R. 1995. Collisional tectonics along the Laurentian margin of the Newfoundland Appalachians. *In* Current Perspectives in the Appalachian–Caledonian Orogen. *Edited by* J.P. Hibbard, C.R. van Staal, and P.A. Cawood. Geological Association of Canada, Special Paper 41, pp. 283–301.

CLARKE, J.M. 1908. Early Devonic history of New York and eastern North America. New York State Museum, Memoir 9, Part 1, 366 p.

CLARKE, J.M. 1909. The Dalhousie Formation. *In* Early Devonic History of New York and Eastern North America. New York State Museum, Memoir 9, Part 2, pp.7–51.

COOPER, G.A. and KINDLE, C.H. 1936. New brachiopods and trilobites from the Upper Ordovician of Percé, Québec. Journal of Paleontology, **10**: 348–372.

CRICKMAY, G.W. 1930. Structure and stratigraphy of the Matapédia Valley, Gaspé, Québec (abstract). Geological Society of America Bulletin, **41**: 116–117.

CRICKMAY, G.W. 1932. Evidence of Taconic orogeny in Matapédia Valley, Québec. American Journal of Science, **24**: 368–386.

DAVIES, J.L. (Compiler) 1979. Geological map of northern New Brunswick. New Brunswick Department of Natural Resources, MineralResources Branch, Map NR-3.

DOSTAL, J., WILSON, R.A., and KEPPIE, J.D. 1989. Geochemistry of Siluro-Devonian Tobique volcanic belt in northern and central New Brunswick (Canada): tectonic implications. Canadian Journal of Earth Sciences, **26**: 1282–1296.

DOSTAL, J., LAURENT, R., and KEPPIE, J.D. 1993. Late Silurian–Early Devonian rifting during dextral transpression in the southern Gaspé Peninsula (Quebec): petrogenesis of volcanic rocks. Canadian Journal of Earth Sciences, **30**: 2283–2294.

DUBA, D. and WILLIAMS-JONES, A.E. 1983. The application of illite crystallinity, organic matter reflectance, and isotope techniques to mineral exploration: a case study in southwestern Gaspé, Quebec. Economic Geology, **78**: 1350–1363.

ETTENSOHN, F.R., DEVER, G.R., and GROW, J. 1988. A paleosol interpretation for profiles exhibiting subaerial exposure "crusts" from the Mississippian of the Appalachian basin. Geological Society of America, Special Paper 216, pp. 49–79.

FYFFE, L.R. and FRICKER, A. 1987. Tectonostratigraphic terrane analysis of New Brunswick. Maritime Sediments and Atlantic Geology, **23**: 113–123.

GENSEL, P.G., CLOUTIER, R., and MCCUTCHEON, S.R. 1997. Devonian plants and fishes of the Gaspé Peninsula, Québec and northern New Brunswick. American Institute of Biological Sciences, Guidebook, Field Trip 22, August 1997.

GIGGIE, K.V. 1999. Ground follow-up to the multi-sensor airborne geophysical survey in central Restigouche County, New Brunswick: results and interpretation. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-9, 41 p.

GOLDHAMMER, R.T.K. and ELMORE, R.D. 1984. Paleosols capping regressive carbonate cycles in the Pennsylvanian Black Prince Limestone, Arizona. Journal of Sedimentary Petrology, **54**: 1124–1137.

GREINER, H.R. 1967. Silurian–Devonian relationships of the Charlo map-area, New Brunswick. *In* International Symposium on the Devonian System, Calgary, Alberta, 1967. *Edited by* D.H. Oswald. Alberta Society of Petroleum Geologists, Vol. 2, pp. 973–979.

GREINER, H.R. 1973. Pointe Verte to Tide Head, Chaleur Bay area, New Brunswick. *In* Geology of New Brunswick, Field Guide to Excursions. *Edited by* N. Rast. New England Intercollegiate Geological Conference, Fredericton, New Brunswick, Trip A7, pp. 58–70.

GREINER, H.R. 1974a. Geology of Campbellton, Oak Bay (east) and Escuminac (west), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Plates 74-59, 74-60, 74-61.

GREINER, H.R. 1974b. Oak Bay (East Half). New Brunswick Department of Natural Resources, Mineral Resources Branch, Plate 74-115.

GREINER, H.R. 1974c. Escuminac (West Half). New Brunswick Department of Natural Resources, Mineral Resources Branch, Plate 74-116.

HAMILTON-SMITH, T. 1970. Stratigraphy and structure of Ordovician and Silurian rocks of the Siegas area, New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Report of Investigation 12, 55 p.

HAMILTON-SMITH, T. 1972. Stratigraphy and structure of Silurian rocks of the McKenzie Corner area, New Brunswick. New Brunswick Department of Natural Resources, Mineral Development Branch, Report of Investigation 15, 26 p.

HON, R., FITZGERALD, J.P., SARGENT, S.L., SCHWARZ, W.D., DOSTAL, J., and KEPPIE, J.D. 1992. Silurian–Early Devonian mafic rocks of the Piscataquis volcanic belt in northern Maine. Atlantic Geology, **28**: 163–170.

HOWARD, W.V. 1926. Devonian volcanic rocks near Dalhousie, New Brunswick. Geological Society of America Bulletin, **37**: 475–496.

IRRINKI, R.R. 1990. Geology of the Charlo area, Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Report of Investigation 24, 118 p.

IRRINKI, R.R. and CROUSE, G.W. 1986. Geology of Sisson Branch Reservoir map area (NTS 21 O/6), New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources Division, Map Report 861, 19 p.

JACOBSON, G., ARAKEL, A.V., AND YIJIAN, C. 1988. The central Australian groundwater discharge zone: evolution of associated calcrete and gypcrete deposits. Australian Journal of Earth Sciences, **35**: 549–565.

JUTRAS, P., PRICHONNET, G., and VON BITTER, P.H. 1999. The La Couleé Formation, a new post-Acadian continental clastic unit bearing groundwater calcretes, Gaspé Peninsula, Québec. Atlantic Geology, **35**: 139–156.

JUTRAS, P., PRICHONNET, G., and UTTING, J. 2001. Newly identified Carboniferous units (the Pointe Sawyer and Chemin-des-Pêcheurs formations) in the Gaspé Peninsula, Quebec; implications regarding the evolution of the northwestern sector of the Maritimes basin. Canadian Journal of Earth Sciences, **38**: 1–19.

KINDLE, C.H.1935. Stratigraphy of the southeastern Gaspé (abstract). Geological Society of America, Proceedings for 1934, p. 354.

KINDLE, C.H. 1936. A geologic map of southeastern Gaspé. The Eastern Geologist, **1**: 1–8.

LACHANCE, S. 1993. Géologie de la Gaspésie, Feuillet 22 B/2-100-0102 et 21 O/15-100-0402. Gouvernement du Québec, Ministère de l'Énergie et de Ressources, Direction générale de l'exploration géologique et minérale, MB 93-40.

LAVOIE, D. and BOURQUE, P.-A. 2001. The history of hydrocarbon exploration in the Silurian–Devonian Gaspé Belt: 100 years of modest success. Bulletin of Canadian Petroleum Geology, **49**: 180–185.

LAVOIE, D., CHI, G., and FOWLER, M.G. 2001. The Lower Devonian Upper Gaspé Limestones in eastern Gaspé: carbonate diagenesis and reservoir potential. Bulletin of Canadian Petroleum Geology, **49**: 346–365.

LEE, H.J. and NOBLE, J.P.A. 1977. Silurian stratigraphy and depositional environments: Charlo–Upsalquitch Forks area, New Brunswick. Canadian Journal of Earth Sciences, **14**: 2533–2542.

LESPÉRANCE, P.J., MALO, M., SHEEHAN, P.M., and SKIDMORE, W.B. 1987. A stratigraphical and faunal revision of the Ordovician–Silurian strata of the Percé area, Québec. Canadian Journal of Earth Sciences, **24**: 117–134.

MALO, M. 1979. L'axe Aroostook–Matapédia au nord de Chandler, Gaspésie, Québec. Thèse de maîtrise, Université Laval, Québec.

MALO, M. 1986. Stratigraphie et structure de l'anticlinorium d'Aroostook–Percé en Gaspésie, Québec. Thèse de doctorat, Université de Montréal, Montréal, Québec.

MALO, M. 1988. Stratigraphy of the Aroostook–Percé Anticlinorium in the Gaspé Peninsula, Quebec. Canadian Journal of Earth Sciences, **25**: 893–908.

MALO, M. and BOURQUE, P.-A. 1993. Timing of the deformation events from Late Ordovician to Mid-Devonian in the Gaspé Peninsula. *In* The Acadian Orogeny: Recent Studies in New England, Maritime Canada, and the Autochthonous Foreland. *Edited by* D.C. Roy. and J.W. Skehan. Geological Society of America, Special Paper 275, pp.101–122.

MALO, M. and KIRKWOOD, D. 1995. Faulting and progressive strain history of the Gaspé Peninsula in post-Taconian time: a review. *In* Current Perspectives in the Appalachian–Caledonian Orogen. *Edited by* J.P. Hibbard, C.R. van Staal and P.A. Cawood. Geological Association of Canada, Special Paper 41, pp. 267–282.

MCGERRIGLE, H.W. 1950. The geology of eastern Gaspé. Québec Department of Mines, Geological Report 35, 168 p.

MESCHEDE, M. 1986. A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb–Zr–Y diagram. Chemical Geology, **56**: 207–218.

NOBLE, J.P.A. 1985. Occurrence and significance of Late Silurian reefs in New Brunswick, Canada. Canadian Journal of Earth Sciences, **22**: 1518–1529.

NOWLAN, G.S. 1983. Biostratigraphic, paleogeographic, and tectonic implications of Late Ordovician conodonts from the Grog Brook Group, northwestern New Brunswick. Canadian Journal of Earth Sciences, **20**: 651–671.

OKULITCH, A.V. 1999. Geological time scale, 1999. Geological Survey of Canada, Open File 3040 (National Earth Science Series, Geological Atlas) – Revision.

PAVLIDES, L. 1966. Meduxnekeag Group and Spragueville Formation of Aroostook County, northeast Maine. *In* Changes in Stratigraphic Nomenclature by the United States Geological Survey, 1965. *Edited by* G.V. Cohee and W.S. West. United States Geological Survey, Bulletin 1244-A, pp. A52–A57.

PAVLIDES, L. 1968. Stratigraphic and facies relationships of the Carys Mills Formation of Ordovician and Silurian age, northeast Maine. United States Geological Survey, Bulletin 1264, 44 p.

PEARCE, J.A. and NORRY, M.J. 1979. Petrogenetic implications of Ti, Zr, Y and Nb variations in volcanic rocks. Contributions to Mineralogy and Petrology, **69**: 33–47.

POOLE, W.H. 1964. Québec and New Brunswick, Restigouche area. *In* Summary of Activities – Field, 1963. *Compiled by* S.E. Jenness. Geological Survey of Canada, Paper 64-1, p. 61.

RICHARDSON, J. 1859. Report of Mr. James Richardson, explorer, addressed to Sir William E. Logan, F.R. and G.S., Provincial Geologist. Geological Survey of Canada, Report of Progress for 1858, pp.105–169.

RICKARDS, R.B. and RIVA, J. 1981. *Glyptograptus? persculptus* (Salter), its tectonic deformation and its stratigraphic significance for the Carys Mills Formation of N.E. Maine, U.S.A. Geological Journal, **16**: 219–235.

RIVA, J. and MALO, M. 1988. Age and correlation of the Honorat Group, southern Gaspé Peninsula. Canadian Journal of Earth Sciences, **25**: 1618–1628.

ROBB, C. 1870. Report on the geology of northwestern New Brunswick. Geological Survey of Canada, Report of Progress for 1866–1869, Part N, pp. 173–209.

ROBB, C. 1872. Supplementary report on the geology of northwestern New Brunswick. Geological Survey of Canada, Report of Progress for 1870–71, pp. 241–251.

RODGERS, J. 1970. The Tectonics of the Appalachians. New York, John Wiley and Sons, 271 p.

ROY, D.C. and MENCHER, E. 1976. Ordovician and Silurian stratigraphy of northeastern Aroostook County, Maine. *In* Contributions to the Stratigraphy of New England. *Edited by* L.R. Page. Geological Society of America, Memoir 148, pp. 25–52.

RYAN, R.J. and ZENTILLI, M. 1993. Allocyclic and thermochronological constraints on the evolution of the Maritimes Basin of eastern Canada. Atlantic Geology, **29**: 187–197.

RYAN, R.J., GRIST, A., and ZENTILLI, M. 1991. The thermal evolution of the Maritimes Basin: evidence from apatite fission track analysis. *In* Nova Scotia Department of Mines and Energy, Report of Activities. *Edited by* D. MacDonald. Nova Scotia Department of Mines and Energy, Report 91-1, pp. 27–32.

ST. PETER, C. 1972. Geology of Upsalquitch, Boland and Two Brooks, map-area K-4. New Brunswick Department of Natural Resources, Mineral Resources Branch, Plate 72-78.

ST. PETER, C. 1974. Geology of Upsalquitch–Robinsonville–Berry Brook, map-area K-3. New Brunswick Department of Natural Resources, Mineral Resources Branch, Plate 75-153.

ST. PETER, C. 1978. Geology of parts of Restigouche, Victoria and Madawaska counties, northwestern New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Report of Investigations 17, 69 p.

ST. PETER, C. 1982. Geology of Juniper–Knowlesville–Carlisle area, New Brunswick, map-areas I-16, I-17, I-18. New Brunswick Department of Natural Resources, Mineral Resources Branch, Map Report 82-1, 82 p.

SANSCHAGRIN, R. 1963. Preliminary report on Grande-Rivière, Gaspé-South County. Québec Department of Natural Resources, PR 487.

SCHUCHERT, C. and COOPER, G.A. 1930. Upper Ordovician and Lower Devonian stratigraphy and paleontology of Percé, Québec. American Journal of Science, **20**: 161–176.

SCHUCHERT, C. and DART, J.D. 1926. Stratigraphy of the Port Daniel–Gascons area of southeastern Québec. Geological Survey of Canada, Museum Bulletin No. 44, pp.35–58.

SKIDMORE, W.B. 1965. Honorat–Reboul area. Québec Department of Natural Resources, Geological Report 107, 30 p.

SUN, S.S. 1982. Chemical composition and origin of the Earth's primitive mantle. Geochimica et Cosmochimica Acta, **46**: 179–192.

TREMBLAY, A., MALO, M. and ST.-JULIEN, P. 1993. Dunnage Zone – Québec. *In* Geology of the Appalachian–Caledonian Orogen in Canada and Greenland. *Edited by* H. Williams. Geological Survey of Canada, Geology of Canada, No. 6, pp. 179–197.

VAN STAAL, C.R. and DE ROO, J.A. 1995. Mid-Paleozoic tectonic evolution of the Appalachian Central Mobile Belt in northern New Brunswick, Canada: collision, extensional collapse and dextral transpression. *In* Current Perspectives in the Appalachian–Caledonian Orogen. *Edited by* J.P. Hibbard, C.R. van Staal and P.A. Cawood. Geological Association of Canada, Special Paper 41, pp.367–389.

VAN STAAL, C.R., WINCHESTER, J.A., and BÉDARD, J.H. 1991. Geochemical variations in Middle Ordovician volcanic rocks of the northern Miramichi Highlands and their tectonic significance. Canadian Journal of Earth Sciences, **28**: 1031–1049.

VAN STAAL, C.R., DEWEY, J.F., MAC NIOCAILL, C., and MCKERROW, W.S. 1998. The Cambrian–Silurian tectonic evolution of the northern Appalachians and British Caledonides: history of a complex, west and southwest Pacific-type segment of Iapetus. *In* Lyell: The Past is the Key to the Present. *Edited by* D.J. Blundell and A.C. Scott. Geological Society, London, Special Publication 143, pp. 199–242.

WALKER, J.A. and MCCUTCHEON, S.R. 1990. Geology of the Upsalquitch Forks area (NTS 21 O/10), New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources Division, Plate 90-24.

WALKER, J.A. and McCutcheon, S.R. 1995. Siluro-Devonian stratigraphy of the Chaleur Bay Synclinorium, northern New Brunswick. *In* Current Research 1994. *Compiled and edited by* S.A.A. Merlini. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Miscellaneous Report 18, pp. 225–244.

WALKER, R.G., and MUTTIE, E. 1973. Turbidite facies and facies associations. *In* Turbidites and deep-water sedimentation. *Edited by* G.V. Middleton and A.H. Bouma. Society of Economic Paleontologists and Mineralogists, Pacific Section, Short Course, Anaheim, California, pp. 119–157.

WHALEN, J.B. 1993. Geology, petrography, and geochemistry of Appalachian granites in New Brunswick and Gaspésie, Québec. Geological Survey of Canada, Bulletin 436, 124 p.

WILLIAMS, S.H., BURDEN, E.T., and MUKHOPADHYAY, P.K. 1998. Thermal maturity and burial history of Paleozoic rocks in western Newfoundland. Canadian Journal of Earth Sciences, **35**: 1307–1322.

WILSON, R.A. 1990. Geology of the New Denmark–Salmon River area, Victoria County, New Brunswick (parts of NTS 21 J/13, 21 J/14, 21 O/3, 21 O/4). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Report of Investigation 23, 67 p.

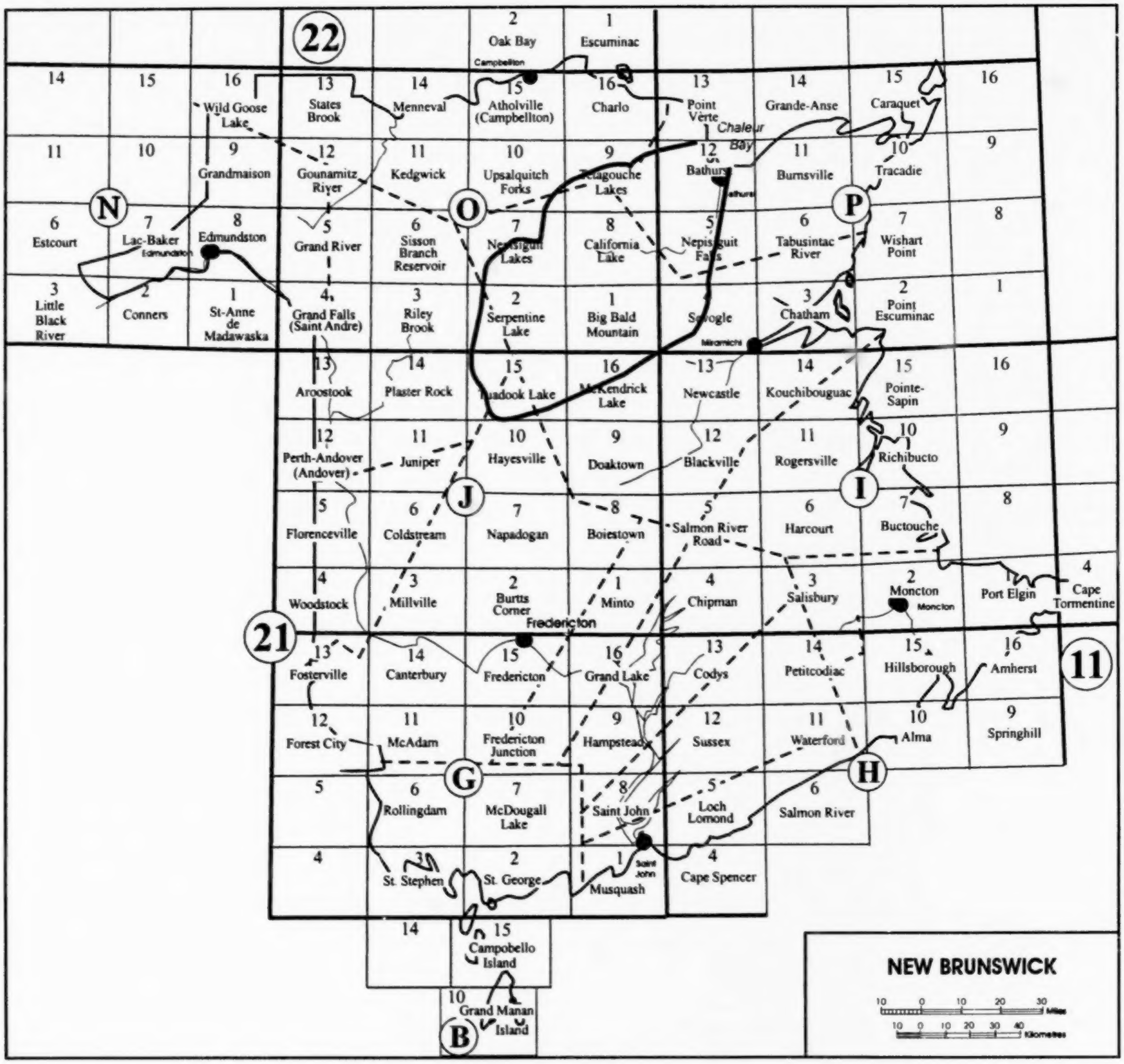
WILSON, R.A. 2000a. Geology of the Popelogan Lake–Lost Pine Lake area (NTS 21 O/15a and b), Restigouche County, New Brunswick. *In* Current Research 1999. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2000-4, pp. 91–136.

WILSON, R.A. 2000b. Geology of Gordon Brook area (NTS 21 O/10g), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-33.

WINCHESTER, J.A. and FLOYD, P.A. 1977. Geochemical distribution of different magma series and their differentiation products using immobile elements. Chemical Geology, **20**: 325–343.

WRIGHT, V.P. and TUCKER, M.E. 1991. Calcretes: an introduction. *In* Calcretes. *Edited by* V.P. Wright and M.E. Tucker. Reprint Series Volume 2 of the International Association of Sedimentologists. Blackwell Scientific Publications, Oxford, pp. 1–22.

INDEX TO 2001–2002 PUBLICATIONS ON THE GEOLOGY OF NEW BRUNSWICK



National Topographic System in New Brunswick
showing the Bathurst Mining Camp

New Brunswick, General

ATLANTIC GEOLOGICAL SOCIETY. 2001. The Last Billion Years — A Geological History of the Maritimes Provinces of Canada. Special Publication No. 15. Nimbus Publishing Ltd., Halifax, Nova Scotia.

CARROLL, B.M.W. (editor) 2001. New Brunswick's mineral industry, 2000. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-3, 111 p.

CARROLL, B.M.W. (editor) 2001. Current Research 2000. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, 143 p.

CARROLL, B.M.W. (editor / rédactrice) 2001. Abstracts, 2001: 26th annual Review of Activities. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 2001-1, 63 p. / Résumés, 2001 : 26e rétrospective annuelle des activités. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Circulaire d'information 2001-1, 63 p.

CARROLL, B.M.W. (editor) 2001. Rétrospective préliminaire de l'industrie minérale au Nouveau-Brunswick, 2000. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Rapport sur les ressources minérales 2001-2, 24 p.

CARROLL, B.M.W. (editor) 2002. Preliminary review of New Brunswick's mineral industry, 2001. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Mineral Resource Report 2002-1, 22 p.

CARROLL, B.M.W. (compiler / compilatrice) 2002. PUBLICATIONS: Available from the New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division (1995–). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Supplementary List, 132 p. / PUBLICATIONS : Publications que les intéressés peuvent obtenir auprès du ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie (1995–). Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, liste supplémentaire, 132 p. (Revised Feb. 2002)

CARROLL, B.M.W. (compiler). 2002. Major mineral developments in New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-37. [page-size; reduction of Plate 99-32A]

LANGTON, J.P., BENTON, P. AND VAN DE POLL, R. 2001. MapTool: a new software program for managing field data. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 55–62.

MCNEILL-DOBBELSTEYN, C.M. and CARROLL, B.M.W. (compilers) 2001. Directory of goods and services for the exploration industry in New Brunswick (December 2001). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 2001-2, 11 p.

MCNEILL-DOBBELSTEYN, C.M. et CARROLL, B.M.W. (compilatrices) 2001. Répertoire des produits et des services offerts à l'industrie de l'exploration minérale au Nouveau-Brunswick (décembre 2001). Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Circulaire d'information 2001-3, 13 p.

MINISTÈRE DES RESSOURCES NATURELLES ET DE L'ÉNERGIE DU NOUVEAU-BRUNSWICK. 1998. Cart normalisée de quadrillage pour le pétrole et gaz naturel du Nouveau-Brunswick. Division des ressources minières et de l'énergie, Planche 98-72 [échelle : 1:600 000].

Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick. 2000. Géologie du substrat rocheux du Nouveau-Brunswick. Division des ressources minières et de l'énergie, Carte NR-1 (édition de 2000). [échelle : 1:500 000]

Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick. 2001. Une politique provinciale pour l'extraction de la tourbe — une stratégie de développement total pour le secteur de la tourbe au Nouveau-Brunswick. Division des ressources minières et de l'énergie, Dossier public 2001-10, 26 p.

New Brunswick Department of Natural Resources and Energy. 1998. New Brunswick standard oil and natural gas grid map. Minerals and Energy Division, Plate 98-72 [scale: 1:600 000]

New Brunswick Department of Natural Resources and Energy. 2001. A Provincial policy on peat mining — a total development strategy for the New Brunswick peat resource sector. Minerals and Energy Division, Open File 2001-10, 26 p.

St. Peter, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. (revised 2001)

St. Peter, C. 2000. Reflection seismic coverage of onshore and offshore New Brunswick, 1948–1999. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-7, 39 p. (revised 2001)

W.J. Wilson and Associates Ltd. 2002. New process for industrial minerals. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Open File 2002-2, 75 p.

Bathurst Mining Camp, General

McCutcheon, S.R. and Walker, J.A. (compilers) 2001. Volcanogenic massive sulphides of the Bathurst Mining Camp. Geological Associatio of Canada–Mineralogical Association of Canada, 2001 Joint Annual Meeting, St. John's, Newfoundland, Field Trip B7, 89 p.

McCutcheon, S.R., Walker, J.A. and McClenaghan, S.H. 2001. The geological settings of massive sulphide deposits in the Bathurst Mining Camp: a synthesis. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 63–95.

McCutcheon, S.R., Lentz, D.R., van Staal, C.R. and Walker, J.A. 2001. Setting of Zn–Pb–Cu–Ag volcanogenic massive sulfide deposits, Bathurst Mining Camp, northern New Brunswick. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip AB, 12 p.

McCutcheon, S.R., Lentz, D.R., van Staal, C.R. and Walker, J.A. 2001. Excursion to the eastern Bathurst Mining Camp: the Brunswick No. 12, and Austin Brook Zn–Pb–Cu–Ag massive-sulfide deposits, Day 1. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip A-6, 14 p.

McCutcheon, S.R., Lentz, D.R., van Staal, C.R. and Walker, J.A. 2001. Excursion to the northern Bathurst Mining Camp: a transect through the California Lake, Fournier and Tetagouche groups, Day 2. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip AB-1, 14 p.

van Staal, C.R., Wilson, R.A., Rogers, N., Fyffe, L.R., Gower, S.J., Langton, J.P., McCutcheon, S.R., and Walker, J.A. 2002. Geology, Bathurst Mining Camp and surrounding areas, New Brunswick (parts of 21 O, P). Geological Survey of Canada, Open File 4182, 1 colour map (scale: 1:100 000)

11 L, CHARLOTTETOWN

11 L/04, Cape Tormentine

Johnson, S.C. 1995. Carboniferous geology of the Cape Tormentine area (NTS 11 L/04), Westmorland County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 95-8 [scale: 1:50 000; revised 2002]

St. Peter, C. 2001. Carboniferous geological compilation map (1:150 000 scale) of southeastern New Brunswick, comprising NTS quadrangles 21 H/10, 15, 16; 21 I/01, 02; and 11 L/04. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-5 [scale: 1:150 000]

21 B, EASTPORT

21 B/10, Grand Manan Island

Bérubé, D., Olsen, L., and Evans, P. 2002. Coastline changes in The Anchorage Provincial Park, Grand Manan Island, New Brunswick, between 1945 and 2001. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-25 [scale: 1:13 500]

Bérubé, D., Olsen, L., et Evans, P. 2002. Déplacement de la ligne de côte dans le parc provincial The Anchorage, île de Grand Manan, Nouveau-Brunswick, entre 1945 et 2001. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-25 [échelle : 1:13 500]

Fyffe, L.R. and Grant, R.H. 2001. Precambrian and Paleozoic geology of Grand Manan Island: the Ganderian margin of Iapetus. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip A-5, 13 p.

McHone, J.G. 2001. Mesozoic geology of Grand Manan. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip B-6, 16 p.

Pe-Piper, G. and Wolde, B. 2000. Geochemistry of metavolcanic rocks of the Ross Island and Ingalls Head formations, Grand Manan Island, New Brunswick. Atlantic Geology, **36**: 103–116.

21 B/15, Campobello Island

Barr, S.M., White, C.E. and Miller, B.V. 2001. Cambrian granitoid plutons of the Pocologan area and the continuation of the Brookville terrane to the Wolves Islands. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 15–24. [parts of NTS 21 B/15 and 21 G/02, 07]

McHone, J.G. 2001. Mesozoic geology of Grand Manan. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip B-6, 16 p.

McLeod, M.J. and Pickerill, R.K. 2001. Bedrock geology of Campobello Island: remnants of a Silurian arc and back-arc complex in southwestern New Brunswick. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip B-4, 20 p.

McLeod, M.J., Pickerill, R.K. and Lux, R.D. 2001. Mafic intrusions on Campobello Island: implications for New Brunswick–Maine correlations. Atlantic Geology, **37**: 17–40 [parts of NTS 21 B/15; 21 G/02, 03]

21 G, FREDERICTON

21 G/01, Musquash

Barr, S.M. and White, C.E. 2001. Geology of the Dipper Harbour area (NTS 21 G/01d), Saint John and Charlotte counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-30 [scale: 1: 20 000]

Barr, S.M. and White, C.E. 2001. Geology of the Lepreau area (NTS 21 G/01e), Saint John, Kings and Charlotte counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-31 [scale: 1: 20 000]

Barr, S.M. and White, C.E. 2001. Geology of the Chance Harbour area (NTS 21 G/01f and part of G/01c), Saint John County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-33 [scale: 1: 20 000]

Barr, S.M. and White, C.E. 2001. Geology of the Ludgate Lake area (NTS 21 G/01g), Saint John County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-32 [scale: 1: 20 000]

Barr, S.M. and White, C.E. 2001. Geology of the Saint John area (NTS 21 G/08a and part of 21 G/01h), Saint John and Kings counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-36 [scale: 1: 20 000]

Barr, S.M. and White, C.E. 2001. The Kingston Group: A redefined Silurian stratigraphic unit in southern New Brunswick. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 1–14. [parts of 21 G/01, 02, 08, 09 and 21 H/05, 12]

Gingras, M.A. 2001. Sedimentology and ichnology of tidal flats on the Bay of Fundy. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip C-3, 11 p.

Johnson, S.C. 2001. Contrasting geology in the Pocologan River and Long Reach areas: implications for the New River belt and correlations in southern New Brunswick and Maine. Atlantic Geology, **37**: 61–79. [parts of NTS 21 G/01, 02, 08]

Park, A.F. 2001. Carboniferous basement–cover relationships around Maces Bay, southern New Brunswick. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip C-6, 13 p.

21 G/02, St. George

Barr, S.M. and White, C.E. 2001. Geology of the Seeleys Cove area (NTS 21 G/02b and parts of G/02c and g), Charlotte County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-34 [scale: 1: 20 000]

Barr, S.M. and White, C.E. 2001. Geology of the New River Beach area (NTS 21 G/02h and part of G/02a), Charlotte County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-35 [scale: 1: 20 000]

Barr, S.M. and White, C.E. 2001. The Kingston Group: A redefined Silurian stratigraphic unit in southern New Brunswick. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 1–14. [parts of 21 G/01, 02, 08, 09 and 21 H/05, 12]

Barr, S.M., White, C.E. and Miller, B.V. 2001. Cambrian granitoid plutons of the Pocologan area and the continuation of the Brookville terrane to the Wolves Islands. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 15–24. [parts of NTS 21 B/15 and 21 G/02, 07]

Barr, S,M. and White, C.E. 2001. Terranes in the Pocologan area, southern New Brunswick. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip B-2, 14 p.

Dadd, K.A. and Van Wagoner, N.A. 2001. Physical volcanology of the Silurian CVB rocks of Passamaquoddy Bay, southwestern New Brunswick. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip C-2, 13 p.

Gingras, M.A. 2001. Sedimentology and ichnology of tidal flats on the Bay of Fundy. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip C-3, 11 p.

Johnson, S.C. 2001. Contrasting geology in the Pocologan River and Long Reach areas: implications for the New River belt and correlations in southern New Brunswick and Maine. Atlantic Geology, **37**: 61–79. [parts of NTS 21 G/01, 02, 08]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, St. George, New Brunswick, NTS 21 G/02. Geological Survey of Canada, Open File 4212. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-1A [scale: 1: 50 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic anomaly map (residual total field), St. George, New Brunswick, NTS 21 G/02. Geological Survey of Canada, Open File 4212. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-1B [scale: 1: 50 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/02a, b. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-6 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/02c, d. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-7 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/02e, f. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-8 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/02g, h. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-9 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, St. George, Nouveau-Brunswick, SNRC 21 G/02. Commission géologique du Canada, Dossier public 4212. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-1A [échelle : 1:50 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte des anomalies magnétiques (champ total résiduel), St. George, Nouveau-Brunswick, SNRC 21 G/02. Commission géologique du Canada, Dossier public 4212. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-1B [échelle : 1:50 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/02a, b. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-6 [échelle : 1:20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/02c, d. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-7 [échelle : 1:20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/02e, f. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-8 [échelle : 1:20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/02g, h. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-9 [échelle : 1:20 000]

McLeod, M.J., Pickerill, R.K. and Lux, R.D. 2001. Mafic intrusions on Campobello Island: implications for New Brunswick–Maine correlations. Atlantic Geology, **37**: 17–40 [parts of NTS 21 B/15; 21 G/02, 03]

McLeod, M.J. and Fyffe, L.R. 2002. Geology and gold occurrences, Clarence Stream area, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-38A [scale: 1:100 000; NTS 21 G/07; parts of 21 G/02, 03, 06, 10 and 11]

McLeod, M.J. and Fyffe, L.R. 2002. Gold metallogeny, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-38B [NTS 21 G/07; parts of 21 G/02, 03, 06, 10 and 11]

Park, A.F. 2001. Carboniferous basement–cover relationships around Maces Bay, southern New Brunswick. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd

Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip C-6, 13 p.

Pronk, A.G., Friske, P.W.B., and Rennick, M.P. 2002. Au, As, and Sb in stream sediments of the St. George map area (NTS 21 G/02), southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-28 [scale: 1:20 000]

Pronk, T. and Seaman, A.A. 2001. Glacial geology traverse from Fredericton to the Fundy coast. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip B-3, 21 p.

21 G/03, St. Stephen

Dadd, K.A. and Van Wagoner, N.A. 2001. Physical volcanology of the Silurian CVB rocks of Passamaquoddy Bay, southwestern New Brunswick. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip C-2, 13 p.

Gingras, M.A. 2001. Sedimentology and ichnology of tidal flats on the Bay of Fundy. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip C-3, 11 p.

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, St. Stephen, New Brunswick, NTS 21 G/03. Geological Survey of Canada, Open File 4212. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-2A [scale: 1: 50 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic anomaly map (residual total field), St. Stephen, New Brunswick, NTS 21 G/03. Geological Survey of Canada, Open File 4212. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-2B [scale: 1: 50 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/03a, b. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-10 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/03e, f. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-11 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/03g, h. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-12 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, St. Stephen, Nouveau-Brunswick, SNRC 21 G/03. Commission géologique du Canada, Dossier public 4212. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-2A [échelle : 1:50 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte des anomalies magnétiques (champ total résiduel), St. Stephen, Nouveau-Brunswick, SNRC 21 G/03. Commission géologique du Canada, Dossier public 4212. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-2B [échelle : 1:50 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/03a, b. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-10 [échelle : 1:20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/03e, f. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-11 [échelle : 1:20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/03g, h. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-12 [échelle : 1:20 000]

McLeod, M.J., Pickerill, R.K. and Lux, R.D. 2001. Mafic intrusions on Campobello Island: implications for New Brunswick–Maine correlations. Atlantic Geology, **37**: 17–40 [parts of NTS 21 B/15; 21 G/02, 03]

McLeod, M.J. and Fyffe, L.R. 2002. Geology and gold occurrences, Clarence Stream area, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-38A [scale: 1:100 000; NTS 21 G/07; parts of 21 G/02, 03, 06, 10 and 11]

McLeod, M.J. and Fyffe, L.R. 2002. Gold metallogeny, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-38B [NTS 21 G/07; parts of 21 G/02, 03, 06, 10 and 11]

Pronk, A.G., Friske, P.W.B., and Rennick, M.P. 2002. Au, As, and Sb in stream sediments of the St. Stephen map area (NTS 21 G/03), southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-29 [scale: 1:20 000]

Pronk, T. and Seaman, A.A. 2001. Glacial geology traverse from Fredericton to the Fundy coast. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip B-3, 21 p.

21 G/06, Rollingdam

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, Rollingdam, New Brunswick, NTS 21 G/06. Geological Survey of Canada, Open File 4212. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-3A [scale: 1: 50 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic anomaly map (residual total field), Rollingdam, New Brunswick, NTS 21 G/06. Geological Survey of Canada, Open File 4212. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-3B [scale: 1: 50 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/06a, b. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-13 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/06c, d. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-14 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/06e, f. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-15 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/06g, h. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-16 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Rollingdam, Nouveau-Brunswick, SNRC 21 G/06. Commission géologique du Canada, Dossier public 4212. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-3A [échelle : 1:50 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte des anomalies magnétiques (champ total résiduel), Rollingdam, Nouveau-Brunswick, SNRC 21 G/06. Commission géologique du Canada, Dossier public 4212. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-3B [échelle : 1:50 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/06a, b. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-13 [échelle : 1:20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/06c, d. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-14 [échelle : 1:20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/06e, f. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-15 [échelle : 1:20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/06g, h. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-16 [échelle : 1:20 000]

McLeod, M.J. and Fyffe, L.R. 2002. Geology and gold occurrences, Clarence Stream area, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-38A [scale: 1:100 000; NTS 21 G/07; parts of 21 G/02, 03, 06, 10 and 11]

McLeod, M.J. and Fyffe, L.R. 2002. Gold metallogeny, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-38B [NTS 21 G/07; parts of 21 G/02, 03, 06, 10 and 11]

Pronk, A.G., Boldon, G.R., and Allard, S. 2002. Till geochemistry and field data of the Rollingdam (NTS 21 G/06) and McDougall Lake (NTS 21 G/07) map areas, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Open File 2002-4, digital file.

Pronk, A.G., Boldon, G.R., and Allard, S. 2002. Au, Sb, As, and Cu in tills of the Rollingdam (NTS 21 G/06) map area, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-36A [scale: 1:50 000]

Pronk, A.G., Friske, P.W.B., and Rennick, M.P. 2002. Au, As, and Sb in stream sediments of the Rollingdam map area (NTS 21 G/06), southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-30 [scale: 1:20 000]

Pronk, T. and Seaman, A.A. 2001. Glacial geology traverse from Fredericton to the Fundy coast. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip B-3, 21 p.

Thorne, K.G. and Lentz, D.R. 2001. Geological setting of the Clarence Stream gold deposit, southwestern New Brunswick. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip C-5, 16 p.

21 G/07, McDougall Lake

Barr, S.M., White, C.E. and Miller, B.V. 2001. Cambrian granitoid plutons of the Pocologan area and the continuation of the Brookville terrane to the Wolves Islands. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 15–24. [parts of NTS 21 B/15 and 21 G/02, 07]

Friske, P.W.B., McCurdy, M.W., Day, S.J.A., and McNeil, R.J. 2001. Evaluation of total, partial and selective leach data from humus, B-horizon and till: a case study from the Clarence Stream gold property, southern New Brunswick. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 25–45.

Fyffe, L.R. and Riva, J.F.V. 2001. Regional significance of graptolites from the Digdeguash Formation of southwestern New Brunswick. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 47–54.

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, McDougall Lake, New Brunswick, NTS 21 G/07. Geological Survey of Canada, Open File 4212. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-4A [scale: 1: 50 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic anomaly map (residual total field), McDougall Lake, New Brunswick, NTS 21 G/07. Geological Survey of Canada, Open File 4212. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-4B [scale: 1: 50 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/07a, b. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-17 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/07c, d. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-18 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/07e, f. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-19 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/07g, h. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-20 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, McDougall Lake, Nouveau-Brunswick, SNRC 21 G/07. Commission géologique du Canada, Dossier public 4212. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-4A [échelle : 1:50 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte des anomalies magnétiques (champ total résiduel), McDougall Lake, Nouveau-Brunswick, SNRC 21 G/07. Commission géologique du Canada, Dossier public

4212. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-4B [échelle : 1:50 000]

KISS, F., POTVIN, J., COYLE, M., et MCLEOD, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/07a, b. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-17 [échelle : 1:20 000]

KISS, F., POTVIN, J., COYLE, M., et MCLEOD, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/07c, d. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-18 [échelle : 1:20 000]

KISS, F., POTVIN, J., COYLE, M., et MCLEOD, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/07e, f. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-19 [échelle : 1:20 000]

KISS, F., POTVIN, J., COYLE, M., et MCLEOD, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/07g, h. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-20 [échelle : 1:20 000]

MCCUTCHEON, S.R., SINCLAIR, W.D. and KOOIMAN, G.J.A. 2001. The Late Devonian Mount Pleasant caldera: geological setting of a W–Mo–Sn–In deposit in southwestern New Brunswick. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip B-5, 14 p.

MCLEOD, M.J. and FYFFE, L.R. 2002. Geology and gold occurrences, Clarence Stream area, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-38A [scale: 1:100 000; NTS 21 G/07; parts of 21 G/02, 03, 06, 10 and 11]

MCLEOD, M.J. and FYFFE, L.R. 2002. Gold metallogeny, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-38B [NTS 21 G/07; parts of 21 G/02, 03, 06, 10 and 11]

PRONK, A.G., BOLDON, G.R., and ALLARD, S. 2002. Till geochemistry and field data of the Rollingdam (NTS 21 G/06) and McDougall Lake (NTS 21 G/07) map areas, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Open File 2002-4, digital file.

PRONK, A.G., BOLDON, G.R., and ALLARD, S. 2002. Au, Sb, As, and Cu in tills of the McDougall Lake (NTS 21 G/07) map area, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-36B [scale: 1:50 000]

PRONK, A.G., FRISKE, P.W.B., and RENNICK, M.P. 2002. Au, As, and Sb in stream sediments of the McDougall Lake map area (NTS 21 G/07), southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-31 [scale: 1:20 000]

PRONK, T. and SEAMAN, A.A. 2001. Glacial geology traverse from Fredericton to the Fundy coast. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip B-3, 21 p.

THORNE, K.G., HOY, D. and LENTZ, D.R. 2001. Field Guidebook: The Clarence Stream gold deposit, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2001-9, 20 p.

21 G/08, Saint John

BARR, S.M. and WHITE, C.E. 2001. Geology of the Saint John area (NTS 21 G/08a and part of 21 G/01h), Saint John and Kings counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-36 [scale: 1: 20 000]

BARR, S.M. and WHITE, C.E. 2001. Geology of the Grand Bay area (NTS 21 G/08b), Saint John and Kings counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-37 [scale: 1: 20 000]

BARR, S.M. and WHITE, C.E. 2001. Geology of the Loch Alva area (NTS 21 G/08c and part of 21 G/08d), Saint John and Kings counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-38 [scale: 1: 20 000]

BARR, S.M. and WHITE, C.E. 2001. Geology of the Centreton area (NTS 21 G/08h and part of 21 G/08g), Kings County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-39 [scale: 1: 20 000]

BARR, S.M. and WHITE, C.E. 2001. The Kingston Group: A redefined Silurian stratigraphic unit in southern New Brunswick. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 1–14. [parts of 21 G/01, 02, 08, 09 and 21 H/05, 12]

JOHNSON, S.C. 2001. Stratigraphy of Neoproterozoic and Devonian–Carboniferous volcanic and epiclastic rocks in the Long Reach and Taylors Island areas, New Brunswick. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip A-2, 15 p.

JOHNSON, S.C. 2001. Contrasting geology in the Pocologan River and Long Reach areas: implications for the New River belt and correlations in southern New Brunswick and Maine. Atlantic Geology, **37**: 61–79. [parts of NTS 21 G/01, 02, 08]

MILLER, R.F. 2001. History of geological investigation of Saint John, New Brunswick. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip C-1, 18 p.

21 G/09, Hampstead

BARR, S.M. and WHITE, C.E. 2001. The Kingston Group: A redefined Silurian stratigraphic unit in southern New Brunswick. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 1–14. [parts of 21 G/01, 02, 08, 09 and 21 H/05, 12]

MCLEOD, M.J. 2000. Geology of the Wickham area (NTS 21 G/09h), Queens and Kings counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-31. [scale: 1:20 000]

MCLEOD, M.J. and JOHNSON, S.C. 2000. Bedrock geology of the Belleisle Bay–Long Reach area, southern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-36 [scale: 1:20 000; NTS 21 G/09a and 21 H/12d]

ST. PETER, C. 2000. Carboniferous geology of the southwestern New Brunswick platform (Marysville subbasin). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-16

[scale: 1:150 000; revised 2001; NTS 21 G/10, 15, 21 J/2, 7, parts of 21 G/9, 11, 14, 16, parts of 21 J/1, 3, 6, 8]

21 G/10, Fredericton Junction

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, Fredericton Junction, New Brunswick, NTS 21 G/10. Geological Survey of Canada, Open File 4212. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-5A [scale: 1: 50 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic anomaly map (residual total field), Fredericton Junction, New Brunswick, NTS 21 G/10. Geological Survey of Canada, Open File 4212. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-5B [scale: 1: 50 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/10a, b. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-21 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/10c, d. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-22 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/10e, f. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-23 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., and McLeod, M.J. 2002. Magnetic first vertical derivative map, New Brunswick, NTS 21 G/10g, h. Geological Survey of Canada, Open File 4217. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-24 [scale: 1: 20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Fredericton Junction, Nouveau-Brunswick, SNRC 21 G/10. Commission géologique du Canada, Dossier public 4212. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-5A [échelle : 1:50 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte des anomalies magnétiques (champ total résiduel), Fredericton Junction, Nouveau-Brunswick, SNRC 21 G/10. Commission géologique du Canada, Dossier public 4212. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-5B [échelle : 1:50 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/10a, b. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-21 [échelle : 1:20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/10c, d. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-22 [échelle : 1:20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/10e, f. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-23 [échelle : 1:20 000]

Kiss, F., Potvin, J., Coyle, M., et McLeod, M.J. 2002. Carte de la dérivée première verticale du champ magnétique, Nouveau-Brunswick, SNRC 21 G/10g, h. Commission géologique du Canada, Dossier public 4217. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2002-24 [échelle : 1:20 000]

McLeod, M.J. and Fyffe, L.R. 2002. Geology and gold occurrences, Clarence Stream area, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-38A [scale: 1:100 000; NTS 21 G/07; parts of 21 G/02, 03, 06, 10 and 11]

McLeod, M.J. and Fyffe, L.R. 2002. Gold metallogeny, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-38B [NTS 21 G/07; parts of 21 G/02, 03, 06, 10 and 11]

St. Peter, C. 2000. Carboniferous geology of the southwestern New Brunswick platform (Marysville subbasin). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-16 [scale: 1:150 000; revised 2001; NTS 21 G/10, 15, 21 J/2, 7, parts of 21 G/9, 11, 14, 16, parts of 21 J/1, 3, 6, 8]

Pronk, A.G., Friske, P.W.B., and Rennick, M.P. 2002. Au, As, and Sb in stream sediments of the Fredericton Junction map area (NTS 21 G/10), southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-32 [scale: 1:20 000]

Pronk, T. and Seaman, A.A. 2001. Glacial geology traverse from Fredericton to the Fundy coast. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip B-3, 21 p.

21 G/11, McAdam

McLeod, M.J. and Fyffe, L.R. 2002. Geology and gold occurrences, Clarence Stream area, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-38A [scale: 1:100 000; NTS 21 G/07; parts of 21 G/02, 03, 06, 10 and 11]

McLeod, M.J. and Fyffe, L.R. 2002. Gold metallogeny, southwestern New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Plate 2002-38B [NTS 21 G/07; parts of 21 G/02, 03, 06, 10 and 11]

Pronk, T. and Seaman, A.A. 2001. Glacial geology traverse from Fredericton to the Fundy coast. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip B-3, 21 p.

St. Peter, C. 2000. Carboniferous geology of the southwestern New Brunswick platform (Marysville subbasin). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-16 [scale: 1:150 000; revised 2001; NTS 21 G/10, 15, 21 J/2, 7, parts of 21 G/9, 11, 14, 16, parts of 21 J/1, 3, 6, 8]

21 G/13, Fosterville

Fyffe, L.R.2001. Geology of the Pocowogamis Stream area (NTS 21 G/13g), York and Carleton counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-46 [scale: 1:20 000]

Fyffe, L.R. 2001. Stratigraphy and geochemistry of Ordovician volcanic rocks of the Eel Riveraea, west-central New Brunswick. Atlantic Geology, **37**: 81-101.

21 G/14, Canterbury

McLeod, M.J. and Johnson, S.C. 1998. Bedrock geological compilation of the Canterbury area (NTS 21 G/14), York County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 98-32 [scale: 1:50 000; revised 2001]

St. Peter, C. 2000. Carboniferous geology of the southwestern New Brunswick platform (Marysville subbasin). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-16 [scale: 1:150 000; revised 2001; NTS 21 G/10, 15, 21 J/2, 7, parts of 21 G/9, 11, 14, 16, parts of 21 J/1, 3, 6, 8]

21 G/15, Fredericton

Pronk, T. and Seaman, A.A. 2001. Glacial geology traverse from Fredericton to the Fundy coast. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip B-3, 21 p.

St. Peter, C. 2000. Carboniferous geology of the southwestern New Brunswick platform (Marysville subbasin). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-16 [scale: 1:150 000; revised 2001; NTS 21 G/10, 15, 21 J/2, 7, parts of 21 G/9, 11, 14, 16, parts of 21 J/1, 3, 6, 8]

Whitehead, J. 2001. Geology of the Fredericton–Mactaquac Dam area. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip A-1, 12 p.

21 G/16, Grand Lake

St. Peter, C. 2000. Carboniferous geology of the southwestern New Brunswick platform (Marysville subbasin). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-16 [scale: 1:150 000; revised 2001; NTS 21 G/10, 15, 21 J/2, 7, parts of 21 G/9, 11, 14, 16, parts of 21 J/1, 3, 6, 8]

21 H, SUSSEX

St. Peter, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p.

St. Peter, C. 2001. Petroleum geology in the Carboniferous of southeastern New Brunswick. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip A-4, 30 p.

21 H/04, Cape Spencer

Gingras, M.A. 2001. Sedimentology and ichnology of tidal flats on the Bay of Fundy. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip C-3, 11 p.

21 H/05, Loch Lomond

Barr, S.M. and White, C.E. 2001. Geology of the Golden Grove area (NTS 21 H/05d), Kings County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-40 [scale: 1: 20 000]

Barr, S.M. and White, C.E. 2001. Geology of the Quispamsis area (NTS 21 H/05e), Kings County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-41 [scale: 1: 20 000]

Barr, S.M. and White, C.E. 2001. Geology of the Smithtown area (NTS 21 H/05f), Kings County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-42 [scale: 1: 20 000]

Barr, S.M. and White, C.E. 2001. The Kingston Group: A redefined Silurian stratigraphic unit in southern New Brunswick. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 1–14. [parts of 21 G/01, 02, 08, 09 and 21 H/05, 12]

Gingras, M.A. 2001. Sedimentology and ichnology of tidal flats on the Bay of Fundy. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip C-3, 11 p.

21 H/10, Alma

St. Peter, C. 1997. Carboniferous geology of the Alma area (NTS 21 H/10), Albert and Westmorland counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 97-10 [scale: 1:50 000; revised 2002]

St. Peter, C. 2001. Carboniferous geological compilation map (1:150 000 scale) of southeastern New Brunswick, comprising NTS quadrangles 21 H/10, 15, 16; 21 I/01, 02; and 11 L/04. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-5 [scale: 1:150 000]

Webb, T.C. 2002. Geology, development history, and exploration alternatives for gypsum resources at Cape Maringouin (parts of NTS 21 H/10, 21 H/15 and 21 H/16), Westmorland County, southeastern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2001-8, 28 p.

21 H/11, Waterford

St. Peter, C.J. 2002. Bedrock geology of the McCully natural gas field area, Moncton Subbasin (parts of NTS 21 H/11, 12, 13, and 14), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-33 [scale: 1:50 000]

21 H/12, Sussex

Barr, S.M. and White, C.E. 2001. The Kingston Group: A redefined Silurian stratigraphic unit in southern New Brunswick. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 1–14.

Barr, S.M. and White, C.E. 2001. Geology of the Dickie Mountain area (NTS 21 H/12c, part of 21 H/12b), Kings County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-43 [scale: 1: 20 000]

Barr, S.M. and White, C.E. 2001. Geology of the Hoyts Mountain area (NTS 21 H/12d), Kings County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-44 [scale: 1: 20 000]

Barr, S.M. and White, C.E. 2001. Geology of the Kiersteadville area (NTS 21 H/12f, part of 21 H/12g), Kings County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-45 [scale: 1: 20 000]

Barr, S.M. and White, C.E. 2001. The Kingston Group: A redefined Silurian stratigraphic unit in southern New Brunswick. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 1–14. [parts of 21 G/01, 02, 08, 09 and 21 H/05, 12]

Johnson, S.C. 2001. Bedrock geology of the Springfield area (NTS 21 H/12f), southern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-48 [scale: 1:20 000]

21 H/14, Petitcodiac

St. Peter, C.J. 1995. Bedrock geology of Havelock/Cornhill area (NTS 21 H/14f), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 95-22A [scale: 1:20 000; revised 2001]

St. Peter, C.J. 1995. Bedrock geology of Petitcodiac/Intervale area (NTS 21 H/14g), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 95-22B [scale: 1:20 000; revised 2001]

Webb, T.C. 2000. Carboniferous geology and gypsum resources of the Intervale–Hillgrove area (part of NTS 21 H/14), Westmorland County, southeastern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-2 [scale: 1:10 000]

Webb, T.C. 2002. Geology, development history, and exploration alternatives for gypsum and anhydrite resources near Intervale–Hillgrove (part of NTS 21 H/14), Westmorland County, southeastern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2001-7, 36 p.

21 H/15, Hillsborough

Barr, S.M., Hamilton, M.A., White, C.E. and Samson, S.D. 2000. A Late Neoproterozoic age for the Caledonia Mountain Pluton, a high Ti–V layered gabbro in the Caledonia (Avalon) terrane, southern New Brunswick. Atlantic Geology, **36**: 157–166.

Chevron Canada Resources Limited. 1984. Seismic line profiles, Moncton Basin. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plates 89-126 (line 63 Y), 89-206 (line 66 A), 89-207 (line 66 B), 89-208 (line 66 X), 89-131 (line 66 Y), 89-132 (line 67 Y), 89-209 (line 68 B), 89-133 (line 69 Y), 89-210 (line 71), 89-211 (line 71 Y), 89-213 (line 75 X A), 89-214 (line 75 Y). [portions of seismic lines over Stoney Creek field have been released from confidentiality]

St. Peter. C.J. and Johnson, S.C. 1997. Carboniferous geology of the Hillsborough area (NTS 21 H/15), Albert and Westmorland counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 97-8 [scale: 1:50 000; revised 2002]

St. Peter, C. 2001. Carboniferous geological compilation map (1:150 000 scale) of southeastern New Brunswick, comprising NTS quadrangles 21 H/10, 15, 16; 21 I/01, 02; and 11 L/04. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-5 [scale: 1:150 000]

St. Peter, C. 2002. Map of Stoney Creek field showing status of wells and boundaries of oil and gas pools. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-34

Webb, T.C. 2000. Carboniferous geology and gypsum/anhydrite resources of the Hillsborough area (part of NTS 21 H/15), Albert County, southeastern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-31 [scale: 1:10 000]

Webb, T.C. 2000. Carboniferous geology and gypsum/anhydrite resources of the Wilson Brook–Demoiselle Creek area (part of NTS 21 H/15), Albert County, southeastern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-1 [scale: 1:10 000]

Webb, T.C. 2002. Geology, development history, and exploration alternatives for gypsum and anhydrite resources in the Wilson Brook–Demoiselle Creek area (part of NTS 21 H/15), southeastern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2001-4, 41 p.

Webb, T.C. 2002. Geology, development history, and exploration alternatives for gypsum and anhydrite resources near Hillsborough (part of NTS 21 H/15), Albert County, southeastern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2001-6, 58 p.

21 H/16, Amherst

Johnson, S.C. 1997. Carboniferous geology of the Amherst area (NTS 21 H/16 and part of 21 H/09), Westmorland and Albert counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 97-9 [scale: 1:50 000; revised 2002]

St. Peter, C. 2001. Carboniferous geological compilation map (1:150 000 scale) of southeastern New Brunswick, comprising NTS quadrangles 21 H/10, 15, 16; 21 I/01, 02; and 11 L/04. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-5 [scale: 1:150 000]

21 I, MONCTON

21 I/01, Port Elgin

Johnson, S.C. 1995. Carboniferous geology of the Port Elgin area (NTS 21 I/01), Westmorland County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 95-9 [scale: 1:50 000; revised 2002]

St. Peter, C. 2001. Carboniferous geological compilation map (1:150 000 scale) of southeastern New Brunswick, comprising NTS quadrangles 21 H/10, 15, 16; 21 I/01, 02; and 11 L/04. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-5 [scale: 1:150 000]

21 I/02, Moncton

Johnson, S.C. and St. Peter, C.J. 1997. Carboniferous geology of the Moncton area (NTS 21 I/02), Westmorland and Albert counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 97-7 [scale: 1:50 000; revised 2002]

St. Peter, C.J. 1995. Bedrock geology of Berry Mills/Mouth of Turtle Creek area (NTS 21 I/02d), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 95-22C [scale: 1:20 000; revised 2001]

St. Peter, C.J. 1995. Bedrock geology of Lutes Mountain/Indian Mountain area (NTS 21 I/02e), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 95-22D [scale: 1:20 000; revised 2001]

St. Peter, C.J. 1995. Bedrock geology of Shediac River/McQuade Brook area (NTS 21 I/02f), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 95-22E [scale: 1:20 000; revised 2001]

St. Peter, C. 2001. Carboniferous geological compilation map (1:150 000 scale) of southeastern New Brunswick, comprising NTS quadrangles 21 H/10, 15, 16; 21 I/01, 02; and 11 L/04. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-5 [scale: 1:150 000]

21 I/03, Salisbury

St. Peter, C.J. 1995. Bedrock geology of North River/Salisbury area (NTS 21 I/03a), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 95-22F [scale: 1:20 000; revised 2001]

St. Peter, C.J. 1995. Bedrock geology of Killams Mills/Nevers Brook area (NTS 21 I/03b), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 95-22G [scale: 1:20 000; revised 2001]

St. Peter, C.J. 1995. Bedrock geology of Ridge Brook/Havelock area (NTS 21 I/03c), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 95-22H [scale: 1:20 000; revised 2001]

St. Peter, C.J. 1995. Bedrock geology of Canaan/Gallagher Ridge area (NTS 21 I/03h), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 95-22J [scale: 1:20 000; revised 2001]

21 I/07, Bouctouche

Giangioppi, M., Bérubé, D., et Evans, P. 2002. Déplacement de la ligne de côte dans la cellule sédimentaire de cap de Richibouctou–flèche de Bouctouche, Nouveau-Brunswick, entre 1945 et 2000/2001. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 2002-26 [échelle : 1:25 000; partie de SNRC 21 I/10 et 21 I/07]

Giangioppi, M., Bérubé, D., et Evans, P. 2002. Formes et dépôts de tempête de la flèche de Bouctouche, côte sud-est du Nouveau-Brunswick, entre 1945 et 1971. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 2002-35A [échelle : 1:10 000; partie de SNRC 21 I/10 et 21 I/07]

Giangioppi, M., Bérubé, D., et Evans, P. 2002. Formes et dépôts de tempête de la flèche de Bouctouche, côte sud-est du Nouveau-Brunswick, entre 1973 et 2000. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 2002-35B [échelle : 1:10 000; partie de SNRC 21 I/10 et 21 I/07]

Giangioppi, M., Bérubé, D., and Evans, P. 2002. Coastline changes in the sediment cell of Richibouctou Cape–Bouctouche Spit, New Brunswick between 1945 and 2000/2001. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-26 [scale: 1:25 000; parts of NTS 21 I/10 and 21 I/07]

Giangioppi, M., Bérubé, D., and Evans, P. 2002. Storm erosional and depositional features of Bouctouche Spit, southeast coast of New Brunswick, between 1945 and 1971. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-35A [scale: 1:10 000; parts of NTS 21 I/10 and 21 I/07]

Giangioppi, M., Bérubé, D., and Evans, P. 2002. Storm erosional and depositional features of Bouctouche Spit, southeast coast of New Brunswick, between 1973 and 2000. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-35B [scale: 1:10 000; parts of NTS 21 I/10 and 21 I/07]

LeBlanc, J., Bérubé, D. et Robichaud, A. 2001. Taux de déplacement des lignes de côte et de rivage le long de la flèche de Bouctouche, Nouveau-Brunswick, entre 1945 et 1996. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 2001-29 [échelle : 1:10 000; partie de SNRC 21 I/10 et 21 I/07]

LeBlanc, J., Bérubé, D. and Robichaud, A. 2001. Coastline and shoreline rates of change along the Bouctouche Spit, New Brunswick between 1945 and 1996. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-29 [scale: 1:10 000; parts of NTS 21 I/10 and 21 I/07]

21 I/10, Richibucto

Giangioppi, M., Bérubé, D., et Evans, P. 2002. Déplacement de la ligne de côte dans la cellule sédimentaire de cap de Richibouctou–flèche de Bouctouche, Nouveau-Brunswick, entre 1945 et 2000/2001. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 2002-26 [échelle : 1:25 000; partie de SNRC 21 I/10 et 21 I/07]

Giangioppi, M., Bérubé, D., et Evans, P. 2002. Formes et dépôts de tempête de la flèche de Bouctouche, côte sud-est du Nouveau-Brunswick, entre 1945 et 1971. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 2002-35A [échelle : 1:10 000; partie de SNRC 21 I/10 et 21 I/07]

Giangioppi, M., Bérubé, D., et Evans, P. 2002. Formes et dépôts de tempête de la flèche de Bouctouche, côte sud-est du Nouveau-Brunswick, entre 1973 et 2000. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 2002-35B [échelle : 1:10 000; partie de SNRC 21 I/10 et 21 I/07]

Giangioppi, M., Bérubé, D., and Evans, P. 2002. Coastline changes in the sediment cell of Richibouctou Cape–Bouctouche Spit, New Brunswick between 1945 and 2000/2001. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-26 [scale: 1:25 000; parts of NTS 21 I/10 and 21 I/07]

Giangioppi, M., Bérubé, D., and Evans, P. 2002. Storm erosional and depositional features of Bouctouche Spit, southeast coast of New Brunswick, between 1945 and 1971. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-35A [scale: 1:10 000; parts of NTS 21 I/10 and 21 I/07]

Giangioppi, M., Bérubé, D., and Evans, P. 2002. Storm erosional and depositional features of Bouctouche Spit, southeast coast of New Brunswick, between 1973 and 2000. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002-35B [scale: 1:10 000; parts of NTS 21 I/10 and 21 I/07]

LeBlanc, J., Bérubé, D. et Robichaud, A. 2001. Taux de déplacement des lignes de côte et de rivage le long de la flèche de Bouctouche, Nouveau-Brunswick, entre 1945 et 1996. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 2001-29 [échelle : 1:10 000; partie de SNRC 21 I/10 et 21 I/07]

LeBlanc, J., Bérubé, D. and Robichaud, A. 2001. Coastline and shoreline rates of change along the Bouctouche Spit, New Brunswick between 1945 and 1996. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-29 [scale: 1:10 000; parts of NTS 21 I/10 and 21 I/07]

21 J, WOODSTOCK

21 J/01, Minto

AL, T. and BUTLER, K. 2001. Environmental geoscience: acid mine drainage in the Minto coal fields. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip A-3, 10 p.

ST. PETER, C. 2000. Carboniferous geology of the southwestern New Brunswick platform (Marysville subbasin). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-16 [scale: 1:150 000; revised 2001; NTS 21 G/10, 15, 21 J/2, 7, parts of 21 G/9, 11, 14, 16, parts of 21 J/1, 3, 6, 8]

21 J/02, Burtts Corner

WHITEHEAD, J. 2001. Geology of the Fredericton–Mactaquac Dam area. *In* Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R. Pickerill and D. Lentz. 93rd Annual Meeting, New England Intercollegiate Geological Conference, University of New Brunswick, Fredericton, New Brunswick. September 21–23, 2001. Field trip A-1, 12 p.

21 J/03, Millville

ST. PETER, C. 2000. Carboniferous geology of the southwestern New Brunswick platform (Marysville subbasin). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-16 [scale: 1:150 000; revised 2001; NTS 21 G/10, 15, 21 J/2, 7, parts of 21 G/9, 11, 14, 16, parts of 21 J/1, 3, 6, 8]

21 J/06, Coldstream

FRISKE, P.W.B., PRONK, A.G., MCCURDY, M.W., DAY, S.J.A., MCNEIL, R.J., and BOLDON, R. 2002. National Geochemical Reconnaissance: Regional stream sediment and water geochemical data, central New Brunswick. Geological Survey of Canada, Open File 4112, CD-ROM. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2002-1, CD-ROM [NTS 21 J/06 and 21 J/10]

ST. PETER, C. 2000. Carboniferous geology of the southwestern New Brunswick platform (Marysville subbasin). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-16 [scale: 1:150 000; revised 2001; NTS 21 G/10, 15, 21 J/2, 7, parts of 21 G/9, 11, 14, 16, parts of 21 J/1, 3, 6, 8]

SEAMAN, A.A. 2001. The Cloverdale As–Sb dispersal train, and other till geochemical anomalies in the west half of the Coldstream (NTS 21 J/06) map area, Carleton and York counties, New Brunswick. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 97–110.

SEAMAN, A.A. 2002. Till geochemistry of the central and eastern parts of the Coldstream (NTS 21 J/06) map area, York and Carleton counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2002-5, 80 p.

21 J/07, Napadogan

ST. PETER, C. 2000. Carboniferous geology of the southwestern New Brunswick platform (Marysville subbasin). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-16

[scale: 1:150 000; revised 2001; NTS 21 G/10, 15, 21 J/2, 7, parts of 21 G/9, 11, 14, 16, parts of 21 J/1, 3, 6, 8]

21 J/10, Hayesville

Friske, P.W.B., Pronk, A.G., McCurdy, M.W., Day, S.J.A., McNeil, R.J., and Boldon, R. 2002. National Geochemical Reconnaissance: Regional stream sediment and water geochemical data, central New Brunswick. Geological Survey of Canada, Open File 4112, CD-ROM. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2002-1, CD-ROM [NTS 21 J/06 and 21 J/10]

21 J/14, Plaster Rock

Webb, T.C. 2001. Carboniferous geology and gypsum resources of the Plaster Rock area (part of NTS 21 J/14), Victoria County, northwestern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-25 [scale: 1:10 000]

Webb, T.C. 2002. Geology, development history, and exploration alternatives for gypsum near Plaster Rock (part of NTS 21 J/14), Victoria County, New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Open File 2001-3, 29 p.

21 O, CAMPBELLTON

21 O/08, California Lake

Walker, J.A. 2001. The Nine Mile Brook (Willett) massive sulphide occurrence, Bathurst Mining Camp, New Brunswick (NTS 21 O/08E). *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 111–132.

21 O/09, Tetagouche Lakes

Biomet Mining Corporation. 2002. The BioSulphide Process to treat acid mine drainage and Anaconda tailings at Caribou Mine, New Brunswick. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division, Open File 2002-3, 138 p.

21 O/10, Upsalquitch Forks

Kim, J.Y., Pickerill, R.K. and Wilson, R.A. 2000. Palaeophycus bolbitermilus isp. nov. from the Lower Silurian Upsalquitch Formation of New Brunswick, eastern Canada. Atlantic Geology, **36**: 131–137.

Wilson, R.A. 2001. Geology of the Gordon Brook area, NTS 21 O/10g, Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-33 [scale: 1:20 000]

Wilson, R.A. 2001. Geology of the Akroyd Lake area, Restigouche County, New Brunswick (NTS 21 O/10h). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-34 [scale: 1:20 000]

21 O/16, Charlo

LANGTON, J.P. 2001. Geology of the South Charlo River area (NTS 21 O/16d), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-27 [scale: 1:20 000]

LANGTON, J.P. 2001. Geology of the Balmoral area (NTS 21 O/16e), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-28 [scale: 1:20 000]

21 P, BATHURST

21 P/03, Chatham

BÉRUBÉ, D. and EVANS, P. 2001. Recession of the coastline of Middle Island, City of Miramichi, between 1944 and 1996. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2001-47

BÉRUBÉ, D. et EVANS, P. 2001. Recul de la ligne de côte de l'île Middle, ville de Miramichi, entre 1944 et 1996. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2001-47

Conversion Factors:
Imperial and International System of Units (SI)

The following multipliers should be used to convert imperial units to SI units or SI units to imperial units:

CONVERSION FROM SI TO IMPERIAL			CONVERSION FROM IMPERIAL TO SI		
SI Unit	*Multiply by*	*Gives*	*Imperial Unit*	*Multiply by*	*Gives*
LENGTH					
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
AREA					
1cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
VOLUME					
1 cm^3	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.308 0	cubic yards	1 cubic yard	0.764 555	m^3
CAPACITY					
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
MASS					
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.32 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
CONCENTRATION					
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

1 ounce (troy)/ton (short)	20.0	pennyweights/ton (short)
1 pennyweight/ton (short)	0.05	ounce (troy)/ton (short)

NOTE: Conversion factors in bold type are exact.

SOURCE: Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by The Mining Association of Canada in cooperation with the Coal Association of Canada.